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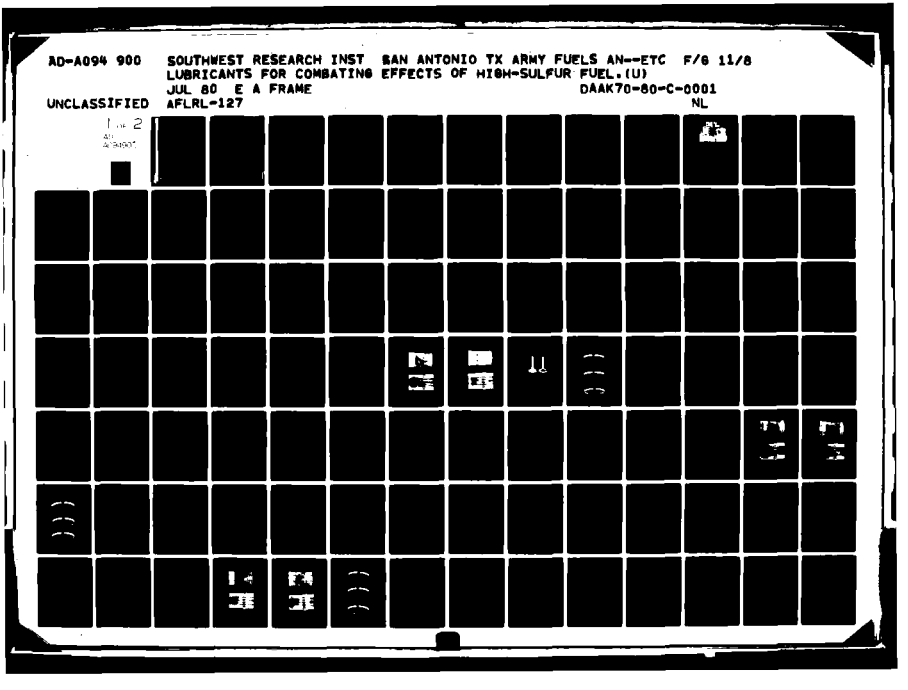

LUBRICANTS FOR COMBATING EFFECTS OF HIGH-SULFUR FUELS

INTERIM REPORT
AFLRL No. 127

by

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Six lubricants were evaluated for their effectiveness in controlling the deleterious effects of using high-sulfur diesel fuel. Two lubricants were identified which have potential to substantially reduce deleterious effects when operating on high-sulfur fuel. A supplemental oil additive used in preservative engine oils was evaluated in three different lubricants with high-sulfur fuel.

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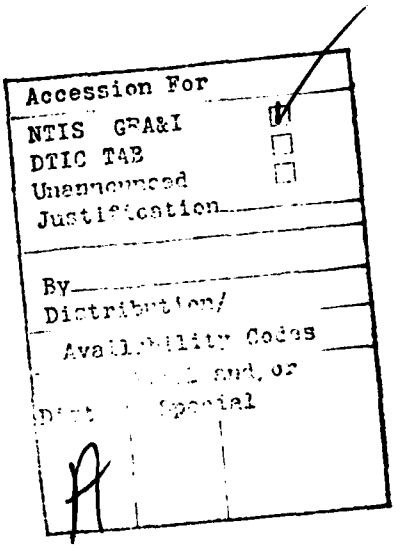
FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at Southwest Research Institute, San Antonio, Texas under Contracts DAAK70-78-C-0001 and DAAK70-80-C-0001. The contract monitor was Mr. F.W. Schaekel of USAMERADCOM, and Mr. T. C. Bowen of the same office was project technical monitor.



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I. INTRODUCTION

A single family of high-output, two-stroke cycle diesel engines is used in a significant portion of the U.S. Army Combat/Tactical Fleet. Table 1 provides a listing of vehicles utilizing this engine family. The engine manufacturer recommends using diesel fuels with less than 0.5 wt% sulfur because "too high a sulfur content results in excessive cylinder wear due to acid build-up in the lubricating oil" (Ref 1). Previous investigations conducted by the United States Army Fuels and Lubricants Research Laboratory (USAFLRL) used an aluminum block engine model 6V53T and revealed engine/fuel/lubricant incompatibilities when using fuels containing greater than 0.5 wt% sulfur and MIL-L-2104C (Ref 2) specification lubricants. The observed incompatibilities included catastrophic piston/ring/exhaust valve failure and relatively high deposit and wear rates (Ref 3). Additional documentation of the detrimental effects of high sulfur diesel fuel can be found in References 4 through 11.

Diesel fuel specification VV-F-800B (Ref 12) allows the use of diesel fuel containing up to 0.7 wt% sulfur outside the continental United States (OCONUS). Based on the fuel sulfur limit allowed in OCONUS and the previous USAFLRL test results with two-cycle diesel engine and high-sulfur fuel, a program was initiated to identify methods of counteracting the detrimental effects of high-sulfur fuel. The program objective was to identify fuel and/or lubricant modifications which would allow continuous operation on diesel fuel containing greater than 0.7 wt% sulfur without significantly reducing engine performance or service life. Identification of such fuel/lubricant modifications would expand the supply of diesel fuel available to the U.S. Army and potentially extend the service life of two-cycle diesel equipment. A previous report (AFLRL No. 105) covered the establishment of low- and high-sulfur fuel baselines using a constant lubricant in the iron block engine model 3-53 (Ref 13). The evaluation of various lubricants for their effectiveness in combating high-sulfur fuel effects was reported in AFLRL No. 109 (Ref 14). Lubricant effectiveness was defined in terms of how well the lubricant performed as compared to the low- and high-sulfur fuel baselines. Two of six lubricants tested (Ref 14) gave significant improvement in the condition of some engine areas; however, none of the engine oils tested would allow the continuous use of high-sulfur fuel with no penalty in engine condition when compared to the use of low-sulfur fuel. The current report covers the evaluation of six additional lubricants for their effectiveness in combating high-sulfur fuel effects.

II. EVALUATION DETAILS

A. Test Engine

An iron-block, two-cycle diesel engine Model 3-53 was utilized as the test engine. This engine is the powerplant used in the M561 1-1/4T tactical truck (Gamma Goat). Additionally, this engine was used to minimize test fuel and engine rebuild costs per test while still utilizing a "real-world" engine. Table 2 gives the characteristics of the 3-53 engine. The engine was fully instrumented and coupled to a laboratory test stand dynamometer as shown in Figure 1.

TABLE 1. ARMY TACTICAL VEHICLES POWERED BY TWO-CYCLE DIESEL ENGINES

Designation	Description	Engine Model
M106A1	Mortar, Self-propelled. 107mm	6V53
M107	Gun, Self-propelled. 175mm	8V71T
M108	Howitzer. Self-propelled. 105mm	8V71T
M109	Howitzer. Medium. 155mm	8V71T
M110	Howitzer. Self-propelled.	8V71T
M113A1	Carrier. Personnel	6V53
M125A1	Mortar. Self-propelled. Full-tracked	6V53
M132A1	Flame Thrower. Self-propelled.	6V53
M548	Carrier. Cargo. Tracked. 3442 kg(6-ton)	6V53
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V53T
M561	Gamma Goat	3-53
M557A1	Carrier. Command Post. Light Tracked	6V53
M578	Recovery Vehicle	8V71T
M746	Heavy Equipment Transporter (Het 70)	12V71T
XM667	Carrier. GM. Equipment. SP	a
XM727	Carrier. GM. Equipment. SP	a
XM730	Carrier. GM. Equipment. SP	a
XM741	Chassis, Gun, AA Artillery, 20mm, SP	a
XM806E1	Recovery Vehicle. FT Armored	a
--	Truck, Dump, 18 140 kg (20-ton), Diesel Electric Driven	6V71

a = Vehicles are powered by either 6V53, 6V53T, or 8V71T (TB-750-652).

TABLE 2. 3-53 ENGINE CHARACTERISTICS

Engine Type	Normally Aspirated, Two-cycle compression ignition, direct injection, uniflow scavenging
Weight (dry), kg (lb)	431 (950)
No. of cylinders, arrangement	3 in-line
Displacement, liter (cu in.)	2.6 (159)
Bore and stroke, cm(in.)	9.84 x 11.43 (3-7/8 x 4-1/2)
Cylinder block material	cast iron (cast iron liners)
Rated power, kW(Hp)	72.3 (97) at 2800 rpm
Maximum torque, Nm(lb-ft)	278 (205) at 1800 rpm
Compression ratio	21 to 1
Fuel system	Unit injector (N 50 needle valve), primary and secondary engine filters
Governor	Variable speed with throttle controls
Oil filter	Full-flow single filter
Oil cooling	Integral heat exchanger using 100% jacket-coolant flow capacity - 13.2 liters (14 qt)
Piston description	
Material/design	Cast iron/trunk type
Ring configuration	1 - Fire ring (rectangular) 3 - Compression rings (rectangular) 2 - Oil rings
Piston cooling	From jet in top of connecting rod

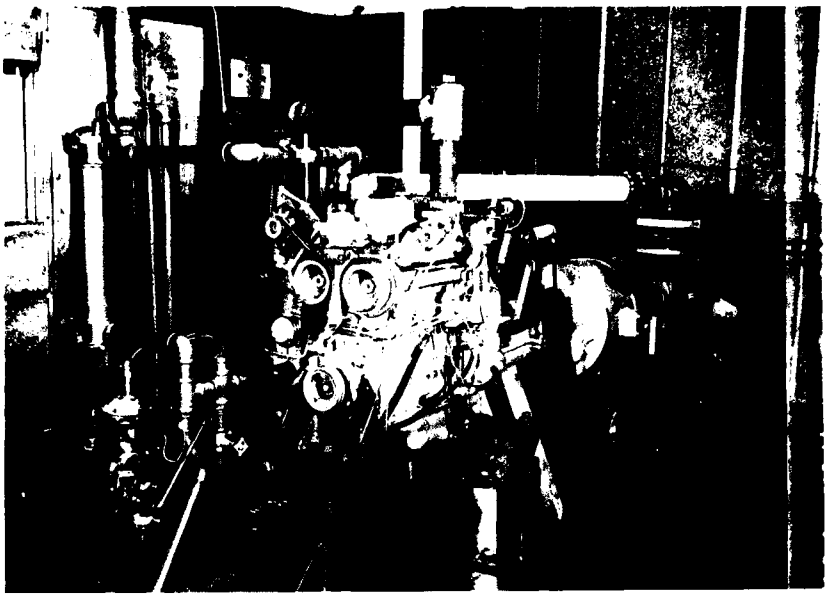

FIGURE 1. 3-53 TEST CELL INSTALLATION
Diesel Engine Model 3-53 Test Facility

B. Test Technique

All tests were conducted using the U.S. Army 210-hour wheeled-vehicle test cycle (Ref 15) which has been correlated to 32,200 km (20,000 miles) of proving ground operation. This test cycle includes alternating periods of full-power and cold idling with an overnight shutdown as shown in Table 3. A complete description of the detailed procedure is presented in Appendix A.

TABLE 3. WHEELED VEHICLE TEST CYCLE/DAY FOR 15 DAYS

Period	Time, hr	Load, %	RPM	Coolant Temp, °C(°F)
1	2	100	2800	96(205)
2	1	0	650	38(100)
3	2	100	2800	96(205)
4	1	0	650	38(100)
5	2	100	2800	96(205)
6	1	0	650	38(100)
7	2	100	2800	96(205)
8	1	0	650	38(100)
9	2	100	2800	96(205)
10	10	----------Shutdown----------		
	24			

Complete test is 15 days at 14 hr/day for 210 hours.

C. Approach

As reported in the literature (Ref 4-11), increasing diesel fuel sulfur content causes increased engine wear and deposition. These effects were quantified in the 3-53 engine by establishing a low-sulfur fuel baseline and a high-sulfur fuel baseline while using a constant lubricant (Ref-13). The low-sulfur fuel baseline serves as an example of the desired performance level. The overall program objective is to identify fuel and/or lubricant modifications which, when used with high-sulfur fuel, will result in engine condition similar to the low-sulfur baseline. The low-sulfur baseline was established using lubricant REO 203 and reference diesel fuel (0.4 wt% S) which is defined by Federal Test Method Standard 791B, Method 341.4. This combination had previously produced excellent results in the 6V53T engine (Ref 3). The high-sulfur fuel (HSF) baseline was established using diesel fuel containing 1.0 wt% sulfur and lubricant REO 203 (Ref 13).

D. Test Details

All tests were conducted in 3-53 engine number 3DI31703. Between tests, new cylinder kits (piston, rings and cylinder liner) and clean exhaust valves were installed. Before test, the engine was measured for 1) liner bore (top/middle/bottom) at thrust/antithrust and front/back positions, 2) piston diameter, and 3) piston ring gap. After experiencing a blower drive gear failure in Test Number 3, the blower drive gears were replaced after each test. Pre- and post-test full load performance tests were determined using the test fuel.

The engine was operated in accordance with the procedure detailed in Appendix A and summarized in Table 3. The following hourly readings and calculations were made to monitor test operation:

	Temperatures	Pressures
Engine Speed	Jacket Coolant-In	Oil Gallery
Engine Load	Jacket Coolant-Out	Blower Discharge
Torque	Oil Sump	Intake Vacuum
Observed Power	Inlet Air (Blower)	Exhaust, Common
Fuel Rate	Exhaust Manifold	Crankcase
BMEP	Fuel at Filter	
BSFC	Fuel at Return	

Minimum and maximum values and averages of these readings and calculations are presented in the Appendix for each test.

After each test, the engine was disassembled, and the following determinations were made:

A. Engine condition ratings in accordance with standard CRC methods (Ref 16, 17) for:
   1. Ring face burning
   2. Ring sticking
   3. Liner scuffing and glazing
   4. Intake port deposits
   5. Ring deposits
   6. Piston deposits
   7. Exhaust valve condition

B. Engine wear measurements for:
   1. Cylinder liner I.D. (top/middle/bottom)
   2. Ring gap
   3. Piston diameter

Oil consumption was calculated and photographs were taken of all three ring sets, and the best and worst cylinder liner and corresponding piston. Used oils were analyzed to determine chemical and physical property changes. The above items are all included in the Appendix for each test.

III. SUMMARIZED RESULTS

This section will present summarized information about the lubricants evaluated, the test fuel used and overall test results. The following section will discuss each test in detail. Table 4 contains a summary of the 3-53 engine tests relevant to this report. Test Number 1 is the low-sulfur fuel (LSF) baseline, which is representative of the desired engine condition at end of test. The average of Test Numbers 4, 12, and 18 is the high-sulfur fuel (HSF) baseline. Test Numbers 15, 17, 19, 20, 21, and 23 were evaluations of various lubricants for their effectiveness in combating high-sulfur fuel effects. This effectiveness will be determined by comparing the after test engine conditions of a subject lubricant to the LSF and HSF baseline engine conditions.

During the time frame of these tests, several batches of high-sulfur diesel fuel (1.0 wt% sulfur) were obtained from the same supplier. The fuel contained all straight run material. According to the manufacturer, 85 percent of the fuel sulfur content of each batch of HSF was naturally-occurring sulfur compounds. The remaining fuel sulfur was ditertiary butyl disulfide. All natural occurring sulfur in the test fuel was from the same refinery stream. Table 5 contains the analyses for the reference DF-2 (Test Number 1) and the various batches of the high-sulfur fuels used in this program.

The properties of the lubricants evaluated during this program are presented in Table 6. The low- and high-sulfur fuel baselines utilized a standard CRC reference engine oil (REO 203) which met the requirements and was qualified under specification MIL-L-2104C. The lubricant from Test Number 15 was a qualified Preservative Engine Oil, which met specification MIL-L-21260B (Ref 18). Test Number 17 was run using a qualified arctic engine oil, specification MIL-L-46167 (Ref 19). Tests 19, 20, and 21 evaluated experimental oils formulated to include the supplemental additive package used in MIL-L-21260B oils. Test Number 23 evaluated a synthetic based lubricant reported by the manufacturer to be of MIL-L-2104C quality level.

Table 7 contains key average operating conditions for these tests. Parameters included are: power, fuel usage, operating temperatures and oil consumption. Table 8 contains a listing of test results including wear measurements for fire ring gap and liner bore change, piston and liner deposition ratings and other pertinent ratings. Table 9 shows a tabulation of the ring sticking

TABLE 4. SUMMARY OF 3-53 ENGINE TESTS

Test Nos.	Fuel Sulfur, wt%	Lubricant Code	Lubricant Performance Level	Comments
1	0.4	REO 203	MIL-L-2104C	Low-Sulfur Fuel baseline
4,12, 18	1.0	REO 203	MIL-L-2104C	High-Sulfur Fuel baseline
15	1.0	AL-7326	MIL-L-21260B	Qualified Preservative Engine Oil
17	1.0	AL-6739	MIL-L-46167	Qualified Arctic Engine Oil
19	1.0	AL-7830	MIL-L-21260B	REO 203 + Supplemental Preservative Oil Additive
20	1.0	AL-7899	High-Output diesel	AL-6739 (Arctic Engine Oil) + Supplemental Preservative Oil Additive
21	1.0	AL-8099	MIL-L-21260B	AL-6856 (Army MIL-L-2104C Reference Oil) + Supplemental Preservative Oil Additive
23	1.0	AL-8423	API SE/CD	Ester-based synthetic SAE 10W/40

TABLE 5. TEST FUEL PROPERTIES

Property	ASTM	Test Number							
		1	4	12	15	17	18,19	20,21	23
Code	Method	Ref DF-2	AL-6765	AL-7178	AL-7289	AL-7475	AL-7766	AL-7965	AL-8926
API°	D 287	33.2	34.6	34.5	34.7	33.6	34.4	34.2	33.7
Sulfur, wt%	D 2622	0.42	1.03	1.05	1.02	1.00	1.03	1.02	0.96
Sulfur, wt%	D 1266	0.42	0.97	1.01	1.02	1.04	1.05	1.03	1.03
Viscosity, cSt at 40°C	D 445	3.20[a]	3.15[a]	2.68	2.86	2.89	2.81	2.87	3.36
Flash Point, °C	D 93	85	ND	73	79	83	82	ND	112
Water & Sediment	D 1796	0.0	0.0	ND	0.0	ND	ND	0.0	ND
Carbon Residue, wt%	D 524	0.10	0.19	0.18	0.19	0.14	ND	0.16	ND
Copper Corrosion	D 130	1A	1B	1A	1A	1A	1A	1A	1A
Cetane Index	D 976	46	50	47	48	47	48	48	50
H, Htg Value.									
MJ/kg	D 240	45.47	44.82	45.00	45.00	ND	ND	45.00	ND
Btu/lb		19,500	19,300	19,400	19,400			19,400	
Distillation, °C	D 86								
IBP		210	197	197	204	211	200	208	218
10%		242	236	225	229	239	238	238	248
50%		271	274	262	263	271	269	269	283
90%		317	315	310	310	311	306	308	323
EP		365	349	352	363	341	344	349	348

ND = Not determined.
a = KVis at 38°C

TABLE 6. TEST LUBRICANT PROPERTIES

Property Code	Method	Test Number 1,4,12,18 REO 203	15 AL-7326	17 AL-6739	19 AL-7830	20 AL-7899	21 AL-8099	23 AL-8423
K Vis, cSt at 40°C	D 445	104.6	106.01	26.76	110.60	27.67	110.31	77.59
K Vis, cSt at 100°C	D 445	11.8	11.81	5.97	12.31	6.08	11.64	12.97
Viscosity Index	D 2270	101	99	179	102	177	92	169
TAN	D 664	3.6	2.0	0.3	1.7	0.4	2.1	5.2
TBN	D 2896	5.4	10.7	8.6	4.8	6.1	13.0	11.2
API Gravity, °	D 287	27.5	27.8	21.1	27.0	21.1	25.3	24.3
Pour Point, °C	D 97	-21	15	-64	ND	ND	ND	-36
Flash Point, °C	D 92	241	246	249	241	ND	ND	198
Carbon Residue	D 524	1.19	1.28	1.48	1.22	1.10	1.68	1.67
Sulfated Ash, wt%	D 874	0.93	1.41	1.55	1.05	1.55	1.78	1.27
Elemental, wt%	Method							
Ba	AA	NIL	NIL	0.95	NIL	0.93	NIL	NIL
Ca	AA(XRF)	0.24	0.36	NIL	0.23	NIL	0.48	0.09
Mg	AA	NIL	NIL	NIL	NIL	NIL	NIL	0.15
Zn	AA	0.09	0.14	NIL	0.14	0.04	0.13	0.12
P	XRF	0.09	0.08	0.01	0.09	0.01	0.08	0.14

ND = Not determined.
XRF = X-ray fluorescence.
NIL = None detected at lower detection limit of method (< ppm for these elements).

TABLE 7. AVERAGE TEST OPERATING CONDITIONS

Parameter	Test Number							
	1(LSF)	4,12,18(HSF)	15	17	19	20	21	23
Power (observed), kW	71	72	69	76	75	77	76	75
Torque,Nm	241	248	237	259	254	264	259	255
BMEP, kPa	586	598	572	621	614	641	627	614
Fuel Rate, kg/hr	19.6	19.2	18.1	19.6	19.5	19.3	19.5	19.7
BSFC, kg/kW-hr	0.276	0.264	0.261	0.258	0.262	0.249	0.257	0.262
Oil Temperature, °C	110	122	119	116	122	114	126	122
Exhaust Temperature, °C	507	523	506	547	547	522	552	518
Total Oil Consumption, kg	15.9	20.4	34.5	19.0	17.7	15.0	24.3	24.1

TABLE 8. TEST RESULTS
Wear, Deposits, and Other Ratings

	Test Number							
	LSF	HSF	High-Sulfur Fuel Test					
	1	4,12,18	15	17	19	20	21	23
Wear								
Average Fire Ring Gap Change, μm	51	237	203	127	381	330	76	127
Average Cylinder Liner Bore Change,								
Front-Back and Thrust-Antithrust, μm	8	16	18	3	15	18	10	20
Thrust-Antithrust only, μm	8	23	25	8	28	25	13	20
Average Liner Scuffing, %	4	41	10	11	37	53	30	34
Average Liner Glazing, %	5	9	12	12	15	0	15	8
Deposition								
Piston WTD* Rating								
Cylinder 1	226	393	362	346	340	341	475	340
Cylinder 2	318	374	437	395	315	369	482	310
Cylinder 3	356	345	528	329	360	342	500	305
Average	300	371	442	357	338	351	486	318
Average Port Restriction, %	7	1	1	3	3	8	3	3
Average Liner Lacquer, %	40	91	88	88	85	100	85	23
Other								
Average Ring Face Burning, % (Fire Ring + 1-3 Compression Rings)	1	32	5	15	14	65	45	52
Used Oil Iron Content, ppm at 210 hr by XRF	110	117	62	64	107	156	72	101

*WTD = Weighted Total Deposit

TABLE 9. RING STICKING SUMMARY

Test No.	Ring Sticking (Cylinder-Ring-Condition)
1(LSF)	#2 - F/R - Sluggish #3 - F/R - 15% Cold Stuck
4(HSF)	#3 - F/R - Sluggish
12(HSF)	#2 - F/R - 60% Cold Stuck
18(HSF)	#1 - CR#2 - 5% Cold Stuck
15	#2 - F/R - Sluggish #3 - F/R - 100% Cold Stuck
17	None
19	None
20	None
21	#1 - F/R - 50% Cold Stuck #2 - F/R - 100% Cold Stuck #3 - F/R - 100% Cold Stuck
23	None

performance for each test. Finally, Table 10 contains the used oil analyses which include the values of selected properties determined at the end of the test (210 hours) and the change in property value from new where available. Having presented the overall summary of test operation and results, each individual test will be discussed in the following section.

IV. DISCUSSION OF RESULTS

In this section, each test will be discussed based on the data presented in Tables 6 through 10. Each test lubricant will be compared to the low- and high-sulfur fuel baselines to provide an overall assessment of lubricant performance in combating high-sulfur fuel effects.

Before discussing the individual tests, the key performance areas of the low- and high-sulfur fuel baselines will be reviewed. The results of the LSF baseline (Table 8) are representative of the desired engine condition at the end of the test. Measured wear (fire ring gap and cylinder liner bore) were low as were liner scuffing and ring face burning. Piston deposit levels were moderate, and no serious ring sticking problems were observed. Compared to the LSF baseline, the HSF baseline had much more severe ring face burning (32 percent vs 1 percent) and cylinder liner scuffing (41 percent vs 4 percent). Measured wear was two to four times more severe for the HSF baseline. Piston cleanliness had deteriorated slightly and ring sticking tendency had increased slightly, but still did not approach problem levels. As shown in Table 10, the used oil from the LSF test was still in satisfactory condition while the

TABLE 10. SUMMARY OF USED OIL ANALYSES

Property	Method	LSF Baseline	HSF Baseline	Test 15	Test 17	Test 19	Test 20	Test 21	Test 23
K. Viscosity at 40°C, cSt	D 445								
at 210 hr		102.8	123.2	122.2	31.72	133.4	31.66	180.85	85.88
Δ from new		-1.8	+18.6	+16.2	+4.96	+22.8	+3.99	+70.54	+8.29
K. Viscosity at 100°C, cSt	D 445								
at 210 hr		12.1	13.4	13.0	6.94	12.77	6.77	16.52	13.42
Δ from new		+0.3	+1.6	+1.2	+0.97	+0.46	+0.69	+4.88	+0.45
TAN at 210 hr	D 664	3.5	3.6	5.4	0.5	3.5	0.9	3.6	5.7
Δ from new		-0.1	0.0	+3.4	+0.2	+1.8	+0.5	+1.5	+0.5
TBN at 210 hr	D 2896	4.4	3.6	10.2	4.3	4.4	5.9	11.9(5.2)	(5.1)
Δ from new	(D 664)	-1.0	-1.8	-0.5	-4.3	-0.4	-0.2	-1.1(-6.4)	(-3.8)
Flash Point, °C	D 97								
at 210 hr		238	252	254	246	258	252	240	232
Δ from new		-3	+11	+8	-3	+17	ND	ND	+34
Carbon Residue, wt%	D 524								
at 210 hr		1.77	2.07	1.92	2.50	1.73	2.34	3.43	2.97
Δ from new		+0.58	+0.88	+0.64	+1.02	+0.51	+1.24	+1.75	+1.30
Sulfated Ash, wt%	D 874								
at 210 hr		1.09	1.19	1.71	1.94	1.23	1.75	2.06	1.61
Δ from new		+0.16	+0.26	+0.30	+0.39	+0.18	+0.20	+0.28	+0.34
Insolubles, wt% (with coagulent)	D 893								
Pentane at 210 hr		0.41	0.40	0.55	0.73	0.43	0.71	0.86	0.98
Benzene (Toluene) at 210 hr		0.28	0.12	0.41	0.62	0.53	0.43	(0.28)	(0.83)
Elemental, ppm	AA(XRF)								
at 210 hr									
Fe		(110)	82(117)	39(62)	83(64)	81(107)	209(156)	56(72)	88(101)
Cr		ND	5	2	5	14	11	2	3
Cu		(<50)	9	4	6	9	6	7	10
Pb		2	43	5	4	13	10	8	14

ND = Not Determined

HSF lubricant had been degraded only slightly more (mainly an increase in flash point and a slight increase in viscosity). The HSF baseline lubricant had increased to an SAE 40 viscosity grade after test, but this was not severe as the new oil itself was on the borderline of being SAE 40. In evaluating the performance of the various test lubricants in combating HSF, our primary objective was to obtain engine condition approaching or equal to the LSF baseline condition when the engine was operated using HSF.

Test Number 15

The lubricant (AL-7326) evaluated in Test Number 15 met the requirements and was qualified under specification MIL-L-21260B (Ref 18). This oil contained a calcium-based detergent-dispersant additive system, with a sulfated ash of 1.41 wt% and a total base number (D 2896) of 10.7. This oil also contained a supplemental zinc additive which is used to impart preservative oil properties to MIL-L-2104C quality oils.

This test resulted in overall improvement in engine condition as compared to the HSF baseline (Table 8). Ring face burning and cylinder liner scuffing approached levels observed in the LSF baseline test. Fire ring gap increase, cylinder liner wear and ring sticking (Table 9) were comparable to the HSF baseline. Piston cleanliness (weighted total deposit ratings) was degraded slightly from the level observed in the HSF baseline tests. As shown in Table 10, the used oil from Test Number 15 was only slightly degraded and had not accumulated excessive wear metal contents. Overall, the use of this preservative type engine oil helped to counteract the deleterious effects of using HSF.

Test Number 17

The lubricant (AL-6739) evaluated in Test Number 17 met the requirements and was qualified under specification MIL-L-46167 (Ref 19). AL-6739 was a synthetic based (diester) lubricant which contained a barium detergent-dispersant additive system. This lubricant was unusual because it had no zinc-containing additives present. Antiwear properties were provided by an organo-phosphorus additive. AL-6739 had a total base number (D 2896) of 8.6 and a sulfated ash of 1.55 wt%.

The use of AL-6739 with high-sulfur fuel resulted in cylinder liner wear and average cylinder liner scuffing which approached levels observed in the LSF baseline. Ring face burning, fire ring gap increase, and piston cleanliness were all improved relative to the average HSF baseline. No ring sticking was observed at end of test. Used oil properties showed that no significant oil degradation had occurred and wear metal accumulations were low. Overall, the use of AL-6739 helped to counteract the deleterious effects of using HSF.

Test Number 19

Because a qualified MIL-L-21260B preservative engine oil helped counteract fuel sulfur effects (Test No. 15), this test was run to determine if the supplemental preservative oil additive package, when blended in a representative MIL-L-2104C lubricant was effective in combating high-sulfur fuel effects. The lubricant evaluated in Test Number 19 was AL-7830, which was composed of REO 203 (baseline lubricant), treated with the recommended amount of the supplemental additive package used in formulating preservative oil

MIL-L-21260B. As shown in Table 6, AL-7830 had slightly higher zinc and sulfated ash contents. The organo zinc compound in the supplemental additive package was not zinc dithiophosphate, as AL-7830 did not have any increase in phosphorus compared to REO 203.

In Test Number 19, slight improvements in ring face burning and piston cleanliness were observed as compared to the HSF baseline. No ring sticking was observed and cylinder liner wear and scuffing remained at the HSF baseline level. Average fire ring gap wear had increased to 1.6 times the level of the HSF baseline. The used oil at end of test was in about the same condition as the HSF baselined used oil. Overall, the oil qualified under MIL-L-21260B (Test Number 15) gave much better performance than AL-7830 in the key areas of ring wear, ring face burning, and cylinder liner scuffing. The addition of the supplemental preservative oil additive package to a representative MIL-L-2104C oil (REO 203) did not result in the desired level of engine condition when using high-sulfur fuel.

Test Number 20

Since the MIL-L-46167, synthetic, diester-based oil (Test No. 17) and the MIL-L-21260B preservative engine oil (Test No. 15) both gave substantial improvement in counteracting high-sulfur fuel effects, it was decided to combine the preservative oil characteristics with the synthetic diester oil. This was accomplished by treating AL-6739 with the recommended amount of supplemental additive package used in formulating preservative oil MIL-L-21260B. The resulting lubricant was designated AL-7899.

Test Number 20, using AL-7899 (treated AL-6739) and HSF, resulted in the deterioration in the condition of several engine areas as compared to Test Number 17, (AL-6739). In fact, fire ring gap increase, ring face burning, and cylinder liner scuffing were all worse than the HSF baseline. The iron content of the used oil at end of test was 209 ppm (by AA) which is about double the level observed in the HSF baseline tests. Piston cleanliness and ring sticking were improved as compared to the HSF baseline. Overall, the supplemental additive package of MIL-L-21260B preservative oil was judged to be antagonistic to AL-6739.

Test Number 21

A final test was made using the MIL-L-21260B supplemental additive package. For Test Number 21, the lubricant (AL-8099) was the U.S. Army reference engine oil (MIL-L-2104C) plus the recommended amount of the preservative oil supplemental additive package. The Army reference oil had been previously tested (Test Number 6) and reported in AFLRL Report No. 109 (Ref 14). Reviewing briefly, Test Number 6 resulted in increased measured wear and piston deposits as compared to the HSF baseline, with the only area of improvement being a slight reduction in cylinder liner scuffing.

AL-8099 (Test Number 21) will be compared against Test Number 6 to determine if the supplemental additive package helped this particular lubricant combat high-sulfur fuel effects and will be compared with the HSF and LSF baselines to determine its overall performance. Compared to the untreated Army reference oil (Test Number 6), AL-8099 had improved performance in controlling fire ring wear and cylinder liner wear, while ring sticking tendencies had in-

creased. Overall, the addition of the preservative oil additive package to the Army reference oil resulted in better performance than the reference oil alone. Compared to the HSF baseline, AL-8099 had substantial improvement in fire ring and cylinder liner wear, but had worse ring face burning, piston deposits, and ring sticking tendencies. While the use of the preservative oil additive package with the Army reference oil did not achieve the desired performance level obtained with the LSF, it was better in two key wear areas than untreated Army reference oil.

Test Number 23

The lubricant (AL-8423) evaluated in Test Number 23 was described by its manufacturer as an "ester based synthetic engine oil" which had met all the requirements for API service classifications SE and CD. AL-8423 contained a magnesium/calcium based detergent-dispersant additive system, with a sulfated ash of 1.27 wt% and a total base number (D 2896) of 11.2.

Compared to the HSF baseline, Test Number 23 had reduced fire ring wear and cylinder liner scuffing. Piston deposits approached the levels observed in the LSF baseline, and no ring sticking tendencies were observed. Cylinder liner wear was about the same as the HSF baseline, but ring face burning area was about 1.6 times more severe with AL-8423. As shown by Table 10, the used oil at end of test had only slight degradation. Overall, AL-8423 showed promise in controlling the high-sulfur fuel effects, except for ring face burning.

V. CONCLUSIONS/RECOMMENDATIONS

A qualitative summary assessment of the performance of the lubricants evaluated in this program is presented in Table 11.

TABLE 11. SUMMARY OF LUBRICANT PERFORMANCE COMPARED TO HIGH- AND LOW-SULFUR FUEL BASELINES

Performance Area	15	17	19	20	21	23
Lube	AL-7326	AL-6739	AL-7830	AL-7899	AL-8099	AL-8423
Fire Ring Wear	●	+	--	--	++	+
Ring Face Distress	++	+	+	--	--	--
Cylinder Liner Wear	●	++	●	●	++	●
Cylinder Liner Scuffing	++	++	●	--	+	+
Piston Cleanliness	--	+	+	+	--	++
Ring Sticking	●	++	++	++	--	++

++ = Improvement approaching LSF baseline.
+ = Improvement relative to HSF baseline.
● = Approximately the same as HSF baseline.
-- = Worse than HSF baseline.

The following conclusions are made based on the work reported herein:

- Two lubricants were identified which have potential for helping to minimize the deleterious effects of HSF. AL-7326 (MIL-L-21260B) showed improvement which approached the desired level in the key areas of ring face burning and cylinder liner scuffing area. AL-6739 (MIL-L-46167) had improvement in all areas listed in Table 11 with cylinder liner wear and liner scuffing showing the greatest improvements. Either of these two lubricants should offer benefits in controlling HSF effects.

- The addition of the supplemental preservative oil additive package to a variety of lubricants produced mixed results. The additive package was antagonistic with AL-6739, while with REO 203 it resulted in reduced ring face distress and increased fire ring wear. The preservative oil package helped the Army reference oil to control high-sulfur fuel effects, but this combination did not achieve the desired performance level. Based on the results, the preservative oil supplemental additive package should not be indiscriminately added to lubricants to serve as a high-sulfur fuel "fix".

- No consistent relationship was found between new lubricant properties and engine condition after tests using HSF.

- Lubricant AL-8423 gave substantial improvements in some of the key areas; however, the increased ring face burning observed with this oil prevents recommendation of it for use with a high-sulfur fuel.

The following recommendations for future effort are offered:

- The 3-53 engine was used in this test program for two reasons. First, it is a "real-world" U.S. Army engine which is also representative of the two-cycle diesel engine family found in the U.S. Army tactical vehicles (Table 1). Second, it was used to minimize test fuel and engine rebuild costs during the screening of lubricants for their effectiveness in combating the effects of HSF. Having identified two promising lubricants in this program, it is now recommended that these lubricants be further evaluated under the more severe conditions found in a higher output, turbocharged U.S. Army two-cycle diesel engine such as the 6V-53T or 8V-71T.

- Fuel additives for combating HSF effects need to be identified and evaluated.

- Research aimed at understanding the basic high-sulfur fuel combustion and engine degradation mechanisms is needed. With this basic HSF information, lubricant additives could be synthesized to specifically counteract the sulfur related engine degradation mechanisms.

- Future Army diesel engine oil specifications should include both two- and four-cycle diesel engine test requirements using HSF.

VI. ACKNOWLEDGMENTS

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Mr. Jesse Cantu	Drafting
Ms. R.S. Hickey	Typing

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APPENDIX A

WHEELED-VEHICLE TEST PROCEDURE

WHEELED-VEHICLE TEST PROCEDURE
DD 3-53 ENGINE

Test No.: _____ Engine Serial No.: _____ Test Cell No.: __

Test Lubricant: _____ Test Fuel: _____

Instructions

1. Pre-Test Preparations.

1.1 Filter Elements. Install new element in oil filter and change oil in air filter bath (using test oil).

1.2 Sump Oil Charge. Charge engine sump to full mark on dipstick with test oil (AL- -L). Close filler cap and motor engine for one minute at low speed (about 500 RPM) to fill oil cooler, filter, and internal oil passages. Recheck level and add to full mark again (should be about 25 lbs).

1.3 Priming Fuel System. After changing over to Ref DF-2 fuel and flushing fuel lines, remove the Allen plug from top of primary fuel filter and fill the filter with fuel, then re-install plug.

1.4 Break-In Procedure. Set jacket coolant-out temp. controller at 205°F. Start engine and idle at 650 RPM for five minutes, then warm up at about 1000 to 1200 RPM for ten minutes. If no engine malfunctions or leakages occur, conduct the following break-in and record complete log sheet readings at end of each setting. Calculate: BHP, Torque, BSFC, BMEP.

Time Minutes	Speed RPM	Load lb-Ft.	Jacket-Out Temperature °F
30	1800	25	205
30	2200	55	205
30	2500	80	205
30	2800	80	205

1.5 Full Load Performance Test. Following the break-in run, conduct a full load performance test run at the following conditions. Allow conditions to stabilize at each speed, then record complete log sheet readings at end of each setting. Calculate BHP, Torque, BSFC, BMEP.

Speed, RPM	Jacket-Out, °F
1600	205
1800	205
2000	205
2200	205
2400	205
2600	205
2800	205

1.6 Valve Clearance Check. Upon completing the full load performance test, stop engine and immediately check the hot clearance of the exhaust valves. Adjust clearances to .023-.025 in, also check injector height per gauge.

1.7 Oil and Fuel Change-Over. Upon completing valve clearance check, drain oil sump and filter. Discard drain and oil filter element. Weigh and record (on oil consumption log) a new oil filter element. Install new oil filter and then charge system with full charge of test oil (AL- -L) as in item 1.2. Record weight of total charge. Change over to test fuel (AL- -F) and flush fuel lines. Replace both fuel filter elements and prime as in item 1.3. Weigh oil blowby can and record (oil consumption log).

1.8 Full Load Performance Test. Following fuel change-over, run full load performance test as in item 1.5.

Check and Adjust Oil Level Before Starting Test.

2. Test.

2.1 Warm-Up. At the start of each day--idle for five minutes, then start test cycle at 2800 RPM.

2.2 Test Conditions. After warm-up, the following test cycle conditions are followed:

Test Cycle for 15 Days

Period	Time, Hrs	Load, %	RPM	Coolant Temp., °F
1	2	100	2800±20	205±2
2	1	0	650±25	100±2
3	2	100	2800	200
4	1	0	650	100
5	2	100	2800	205
6	1	0	650	100
7	2	100	2800	205
8	1	0	650	100
9	2	100	2800	205
10	10	--------Shut Down---------		

Operate at test conditions 14 hours/day for a total of 210 hours. Complete log sheet readings at end of each period. Calculate: BHP, Torque, BSFC, BMEP.

2.3 Daily Cool-Down. After the last test hour each day, reduce the speed to idle (600-650 RPM) for five minutes, (without resetting coolant controller) then stop engine.

2.4 Used Oil Samples. Flush oil filter tap, and withdraw a used oil sample during daily 5-minute cool-down (item 2.3) according to the Oil Consumption Log schedule and record sample weight.

Identify each sample as to test hours, test No. and oil code (AL- -L). Take: 2 oz. sample each day except at 70 and 140 hours take 12 oz. sample. At end of test take 16 oz. sample. Take daily oil samples to Chem Lab for elemental analyses by XRF.

2.5 Oil Additions. New test oil additions, if required, are to be made at the end of each day after shutdown. Allow five minutes for oil to drain back to sump. Add weighed new oil to restore sump level to full by dipstick. Record weight of add-on oil consumption log.

2.6 Final Oil Drain. Upon completion of post test power curves and while engine is warm, drain the sump, saving one gallon of used oil in clean can. Tag can, showing test No., oil code, date, and test hour. Also remove oil filter element, weigh and record.

2.7 Notes and Limits.

(1) Coolant is 50% glycol/50% water.

(2) Coolant Out temperature must be reduced to 100°F within 15 minutes after idle starts.

(3) Limits/Tolerances: Coolant Out Temperature: ±2°F of designated temperature.

Oil Sump Temperature: 265°F max.

Fuel @ Filter Temperature: 90±5°F (105°F max.=shutdown).

(4) No Oil Change during test.

3. After Test.

3.1 Full Load Performance Test. At end of test, run full load performance test as in item 1.5.

3.2 Valve Clearance Check. Upon completing end of test power curve, item 3.1, check hot valve clearances and record.

3.3 Wear and Deposits. Upon disassembly of engine, check wear measurements and deposit ratings (on sheets provided).

3.4 Record amount of fuel used for test.

3.5 Calculations (for AFLRL Cell No. 2):

BHP (obs.) = Load X RPM/3000
Torque (lb-ft) = Load x 1.75
BSFC (lb/Bhp-hr) = lbs Fuel per hr/BHP (obs.)
BMEP (psi) = Torque x 0.474

4. Cell Notebook.

4.1 Keep cell notebook updated (like a diary) at all times. Record what is being done (changes or repairs) to the cell engine, instruments, etc. Record anything unusual and all modifications.

APPENDIX B

3-53 TEST # 15

FUEL: 1% S DF-2 (AL-7289-F)

LUBE: MIL-L-21260B T-1 (AL-7326-L)

START: 10 April 1978

END: 1 May 1978

ENGINE OPERATING DATA (AVG)
TEST #15

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2798	2806	2802	650
Load, lb	97	103	100	
Torque, lb-ft	170	180	175	
BHp obs	91	96	93	
Fuel Rate, lb/hr	37.7	41.4	39.9	
BMEP, psi	81	85	83	
BSFC lb/BHp-hr	0.412	0.441	0.428	
Temperatures, °F				
Jacket Coolant-In	197	198	198	95
Jacket Coolant-Out	203	205	205	100
Oil Sump	244	249	247	
Inlet Air (Blower)	68	92	80	
Exhaust Manifold	910	980	942	
Fuel @ Filter	80	95	91	
Fuel Out	135	146	141	
Pressures				
Oil Gallery, psig	44	45	44	
Blower Discharge, psig	4.4	4.6	4.5	
Intake Vacuum, in. H_2O	6.3	6.7	6.5	
Exhaust, Common, in. Hg	2.2	2.5	2.4	
Oil Consumption, lb			76	

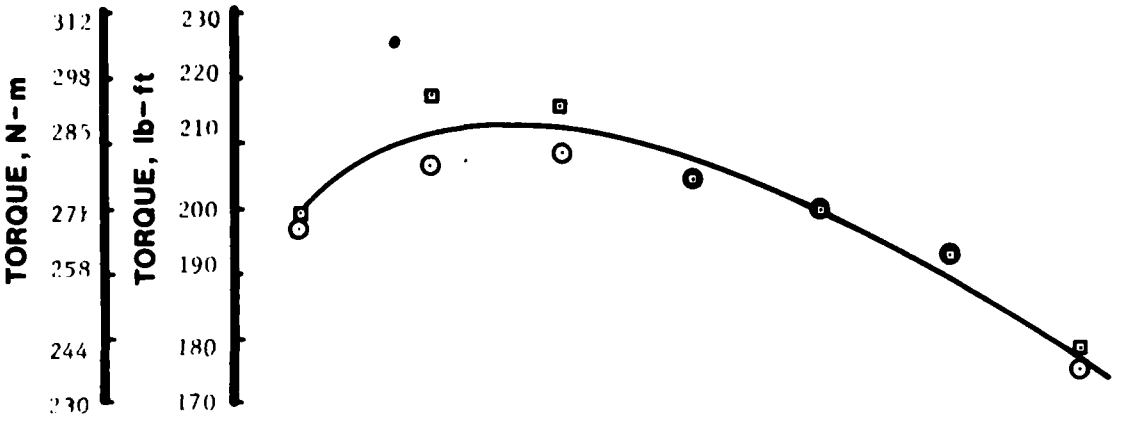
LUBRICANT ANALYSES (AL-7326-L)
TEST #15

Property	ASTM Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D 445	106.0	117.6	120.9	122.2
K. Vis, cS, 100°C	D 445	11.8	12.6	13.0	13.0
VI	D 2270	99	98	100	100
TAN	D 664	2.0	3.3	3.6	5.4
TBN	D 2896	10.7	10.0	10.2	10.2
Insolubles, wt%	D 893				
Pentane A		A	ND	ND	0.12
Benzene A		A	ND	ND	0.05
Pentane B		A	ND	ND	0.55
Benzene B		A	ND	ND	0.41
API Gravity, °	D 287	27.8	ND	ND	27.2
Pour Point, °C	D 97	15	ND	ND	ND
Flash Point, °C	D 92	246	ND	ND	254
Carbon Residue, wt%	D 524	1.28	1.67	1.82	1.92
Sulfated Ash, wt%	D 874	1.41	1.65	1.68	1.71
Elemental	Method				
Ba, ppm	AA	<25	ND	ND	ND
Mg, ppm	AA	9	ND	ND	ND
Ca, wt%	AA	0.35	0.41	0.40	0.44
Zn, wt%	AA	0.14	0.13	0.14	0.15
Na, ppm	AA	12	ND	ND	ND
Cu, ppm	AA	A	3	4	4
Cr, ppm	AA	A	2	2	2
Pb, ppm	AA	A	6	4	5
Fe, ppm	AA	A	27	35	39

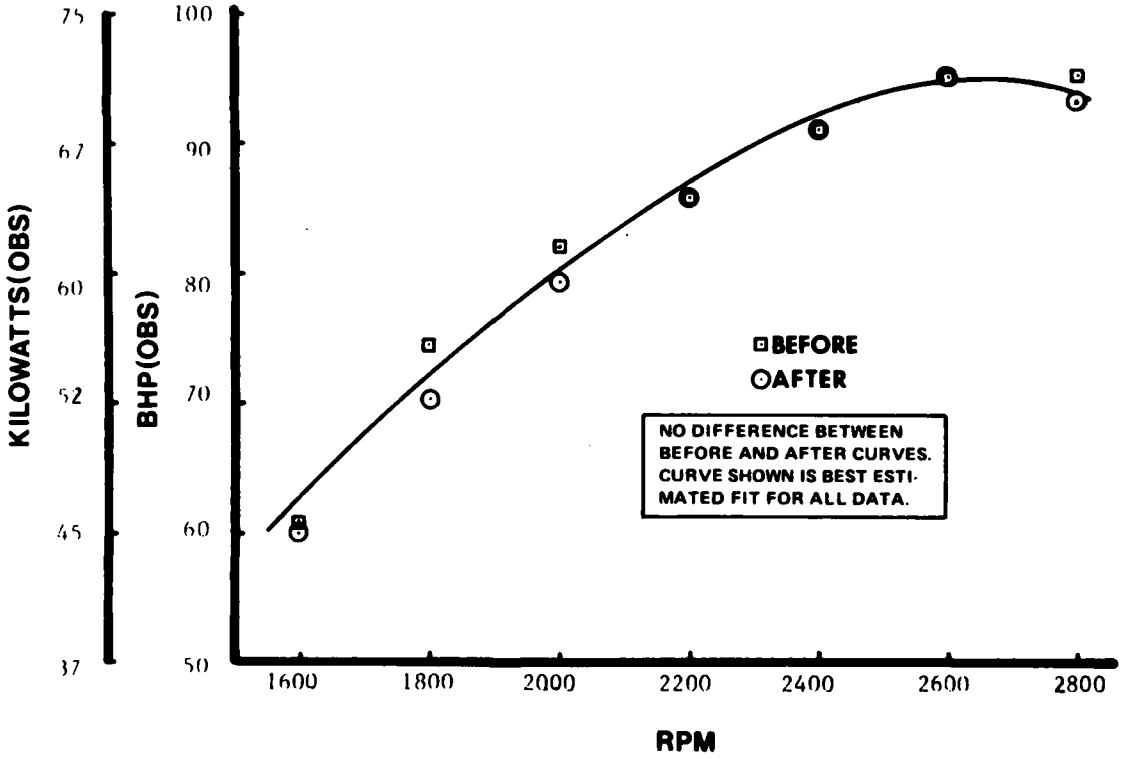
A = Expected to be zero for new oil.
ND = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

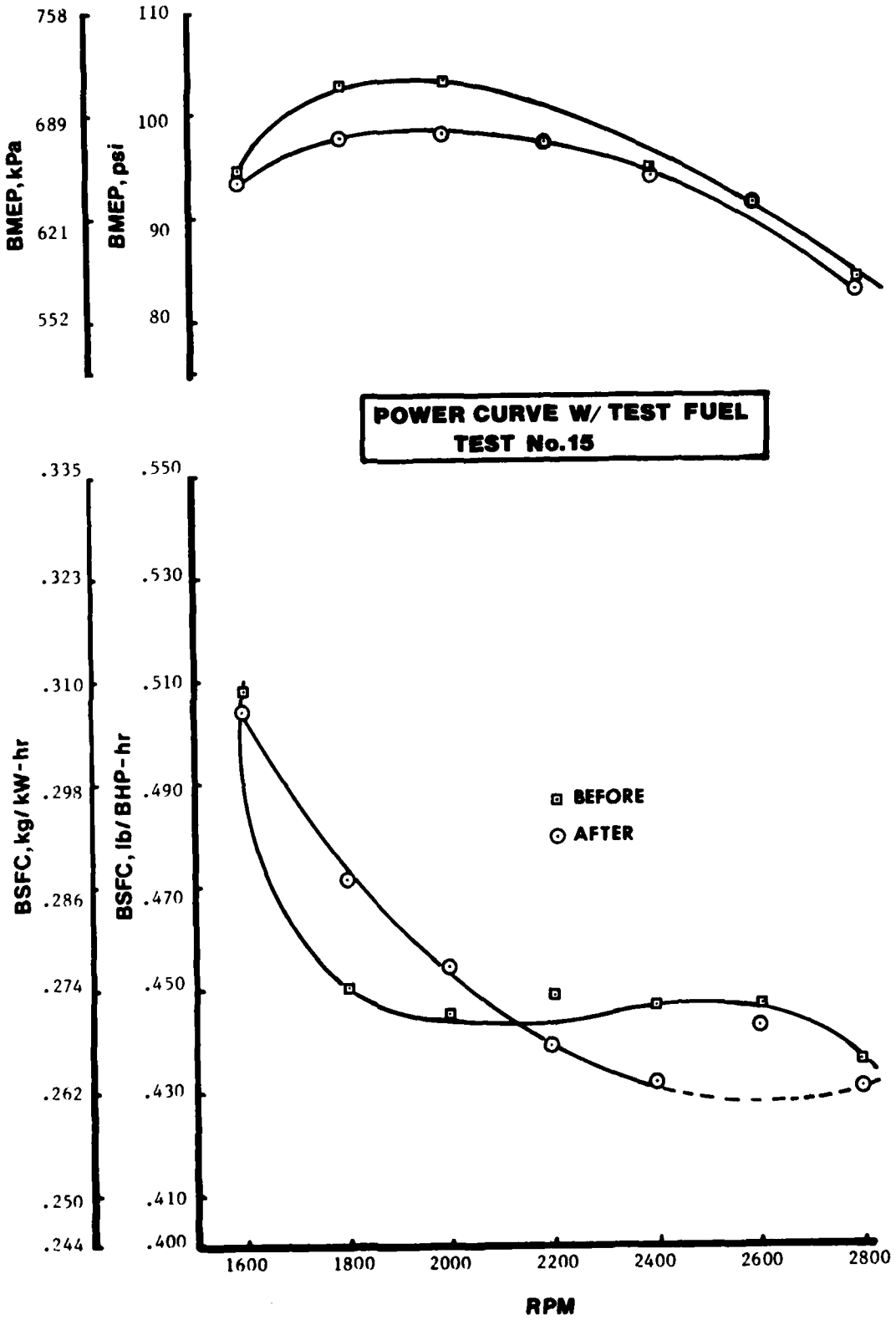
DAILY WEAR METALS BY XRF
TEST #15

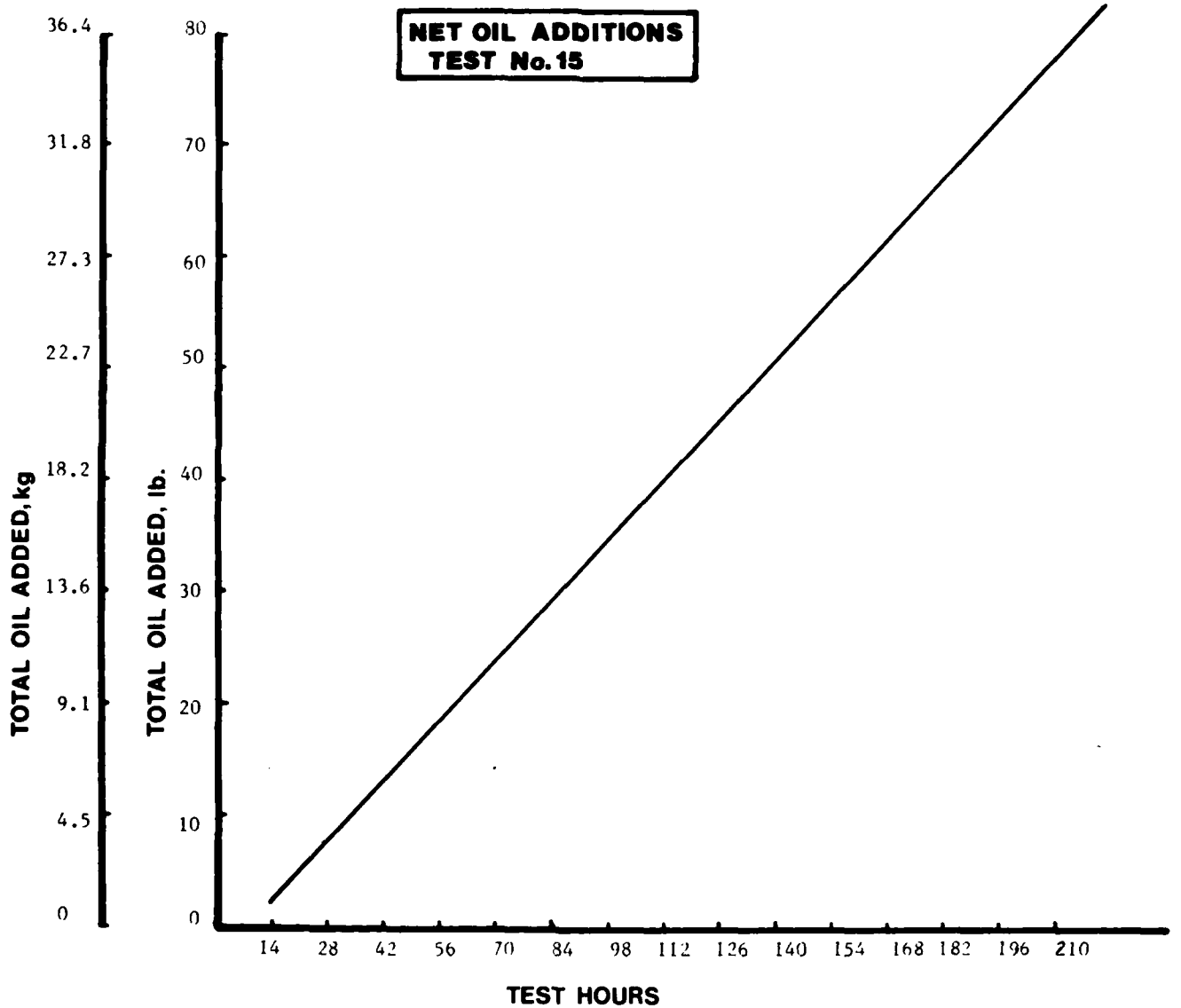
Test Hours	Iron ppm	Other Wear Elements
14	22	None detected
28	37	None detected
42	39	None detected
56	53	None detected
70	51	None detected
84	51	None detected
98	48	None detected
112	53	None detected
126	72	None detected
140	65	None detected
154	62	None detected
168	67	None detected
182	65	None detected
196	62	None detected
210	62	None detected



POWER CURVE W/ TEST FUEL
TEST No.15




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W/ TEST FUEL
TEST No.15
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No. 15
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb.
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #15

	Cylinder Number		
	1	2	3
First Ring	5	1	5
Second Ring	3	1	10
Third Ring	3	1	6
Fourth Ring	1	5	15
Average of all	5%		

N = Normal

RING STICKING
TEST #15

Ring No.	Piston Number		
	1	2	3
1	F	Sluggish	100% cold stuck
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #15

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area				
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	1	5	10	7	15	85
2	1	2	20	11	10	90
3	<1	20	5	12	10	90
Average	1	9	12	10	12	88

PISTON O.D. (IN)
TEST #15

Cylinder	1	2	3
Before	3.8705	3.8710	3.8718
After	3.8702	3.8710	3.8710
Change	0.0003	0.0000	0.0008

PISTON SURFACE CONDITION
TEST #15

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Light scratches - all - - - - - -		
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #15

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	35	30	100
	2	0	25	100
	3	0	0	100
	4	0	0	100
2	1	0	0	55
	2	100	0	90
	3	70	85	70
	4	10	25	95

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #15

Area	Cylinder No. 1	2	3
Head	All - Soot & light carbon, 5% AHC		
Face	ALL - Light to heavy carbon		
Tulip	All - Light to heavy carbon		
Stem	All - 5-10% #9 lacquer		

EXHAUST VALVE SURFACE CONDITIONS
TEST #15

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	light to heavy carbon causing minor leaking		
Seat	light carbon buildup		
Stem	N	N	N
Tip	N	N	N

F = free
N = Normal

RING DEPOSITS
TEST #15

Cylinder Number	Piston	1		2		3	
		CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	80-1/2 AHC	20-9	15-1/2 AHC	5-4, 80-9	NR	NR
	2	0	100-8	0	10-7, 90-8	15-AHC 85-1/2 AHC	0
	3	0	5-5, 95-8	0	50-3, 50-2	0	25-8, 75-7
	4	0	25-3, 75-4	0	80-3, 20-2	0	100-4
ID	1	100-1/2 AHC	0	100-1/2 AHC	0	NR	NR
	2	90-A, 10-1/2 AHC	0	85-A, 15-1/2AHC	0	100-1/2AHC	0
	3	100-1/2 AHC	0	100-1/2 AHC	0	100-1/2AHC	0
	4	10-1/2 AHC	90-9	0	100-9	100-1/2AHC	0
Bottom	1	0	5-7, 95-3	0	5-8,20-3,75-2	NR	NR
	2	0	5-7, 95-3	0	30-6, 70-7	0	100-2
	3	0	10-7, 90-3	0	25-4, 75-2	0	5-8, 95-4
	4	0	20-3, 80-2	0	85-3, 15-2	0	25-5, 70-4, 5-2

NR = Ring not removed from piston

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-7326-L

RATER Lyons DATE 5-3-78
LABORATORY TEST NUMBER 15
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	362

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	15	15.00	85	85.00	35	35.00			10	10.00	70	70.00	50	50.00				
	MHC	0.75																		
	MC	0.50					50	25.00	35	17.50	25	12.50	10	5.00			10	5.00		
	LC	0.25 85	85	21.25	15	3.75	15	3.75			65	16.25	20	5.00	50	12.50	55	13.75		
	VLC	0.15																		
	CARBON RATING		36.25		88.75		63.75		17.50		38.75		80.00		62.50		18.75			
LACQUER	BL	0.100							65	6.50									100	10.00
	DBrL	0.075																		
	AL	0.050															35	1.75		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								6.50								1.75		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			36.25		88.75		63.75		24.00		38.75		80.00		62.50		20.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-7236-L

RATER Lyons DATE 5-3-78
LABORATORY TEST NUMBER 15
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	437

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	LANDS NO. 2 AREA-%	NO. 2 DEMERIT	LANDS NO. 3 AREA-%	NO. 3 DEMERIT	LANDS NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON HC	1.00	15	15.00	70	70.00					25	25.00	60	60.00	35	35.00				
CARBON MHC	0.75					40	30.00												
CARBON MC	0.50	15	7.50							20	10.00	10	5.00						
CARBON LC	0.25	70	17.50	30	7.50	30	7.50			55	13.75			65	16.25	25	6.25		
CARBON VLC	0.15					30	4.50	20	3.00			15	2.25						
CARBON RATING		40.00		77.50		42.00		3.00		48.75		67.25		51.25		6.25			
LACQUER BL	0.100							80	8.00			15	1.50			60	6.00	100	10.00
LACQUER DBrL	0.075															15	1.125		
LACQUER AL	0.050																		
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING								8.00				1.50				7.125		10.00	
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		40.00		77.50		42.00		11.00		48.75		68.75		51.25		13.375		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS _____
TEST LABORATORY _____
LUBRICANT AL-7326-L

RATER Lyons DATE 5-3-78
LABORATORY TEST NUMBER 15
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7289-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	528

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	100	100	90	90.00	40	40.00			75	75.00	60	60.00	75	75.00				
	MHC	0.75																		
	MC	0.50			10	5.00							20	10.00						
	LC	0.25					60	15.00	25	6.25	25	6.25	20	5.00	25	6.25	20	5.00		
	VLC	0.15							75	11.25										
	CARBON RATING		100.00		95.00		55.00		17.50		81.25		75.00		81.25		5.00			
LACQUER	BL	0.100															80	8.00	100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING																8.00		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		95.00		55.00		17.50		81.25		75.00		81.25		13.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN.)
TEST #15

Cylinder No.		Front/Back Parallel to Crank			Thrust/Antithrust Perpendicular to Crank		
		Top	Middle	Bottom	Top	Middle	Bottom
1.	After	3.8758	3.8758	3.8763	3.8767	3.8764	3.8764
	Before	3.8754	3.8754	3.8752	3.8754	3.8753	3.8751
	Δ	0.0004	0.0004	0.0011	0.0013	0.0011	0.0013
2.	After	3.8758	3.8759	3.8760	3.8768	3.8765	3.8762
	Before	3.8755	3.8756	3.8757	3.8757	3.8757	3.8757
	Δ	0.0003	0.0003	0.0003	0.0011	0.0008	0.0005
3.	After	3.8755	3.8753	3.8754	3.8768	3.8767	3.8759
	Before	3.8753	3.8755	3.8760	3.8756	3.8755	3.8758
	Δ	0.0002	-0.0002	-0.0006	0.0012	0.0012	0.0001

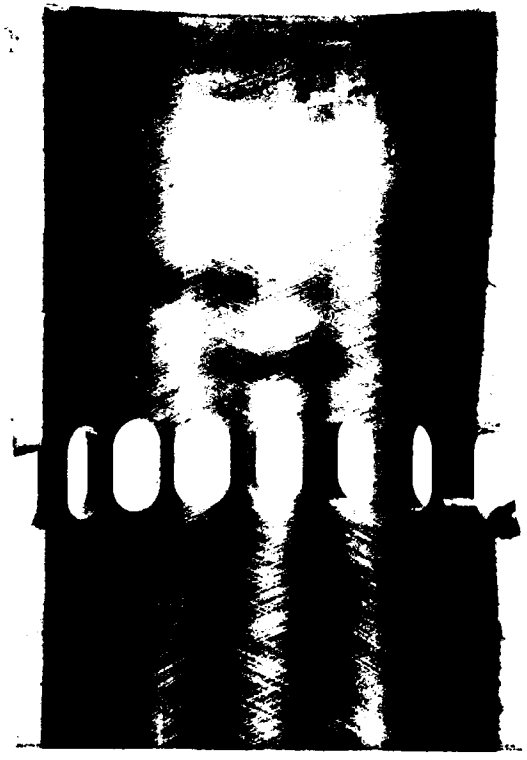
Average (All) 0.0007
Average T/AT 0.0010

PISTON RING GAP (IN.)
TEST #15

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.046	0.028	0.031	0.030	0.023	0.023	0.023	0.023
	Before	0.035	0.027	0.030	0.029	0.018	0.018	0.018	0.018
	Δ	0.011	0.001	0.001	0.001	0.005	0.005	0.005	0.005
2.	After	0.037	0.021	0.023	0.022	0.025	0.025	0.024	0.025
	Before	0.032	0.022	0.023	0.023	0.020	0.021	0.019	0.020
	Δ	0.005	-0.001	0	0.001	0.005	0.004	0.005	0.005
3.	After	stuck	0.036	0.027	0.028	0.023	0.025	0.023	0.023
	Before	0.032	0.035	0.027	0.027	0.018	0.018	0.019	0.019
	Δ		0.001	0	0.001	0.005	0.007	0.004	0.004

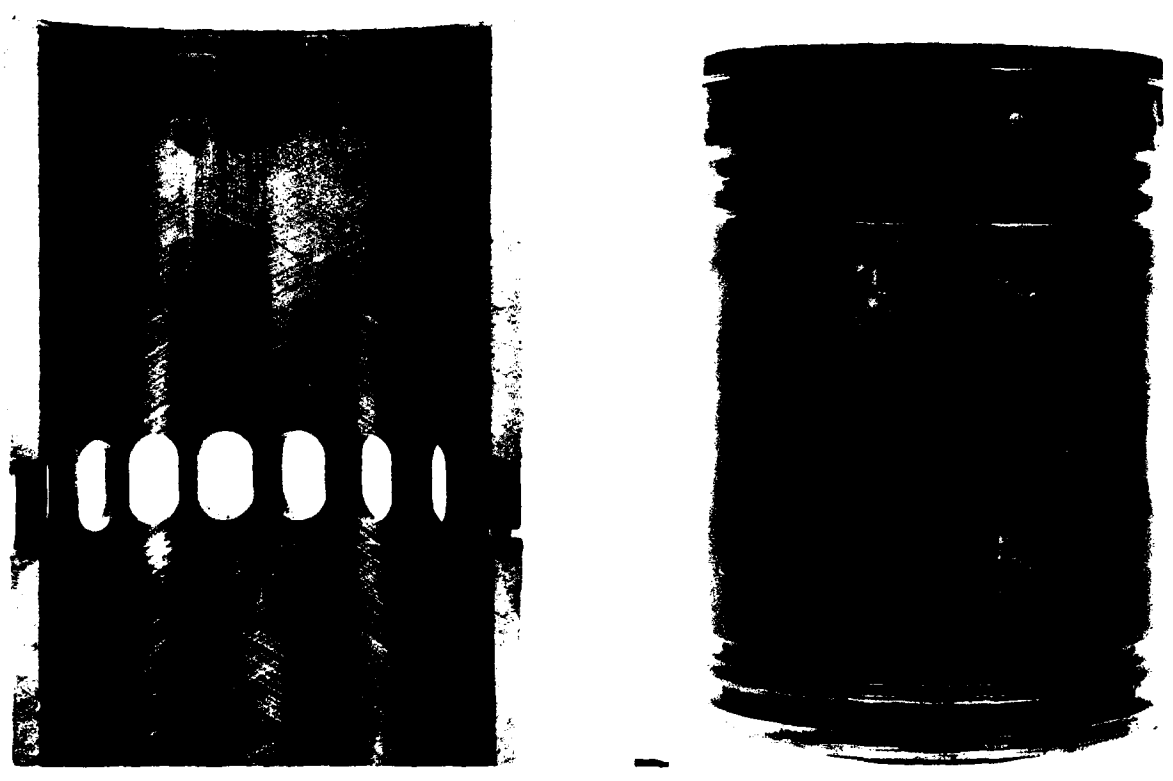
Avg F/R (#1) Wear 0.008

PISTON AND CYLINDER LINER CONDITION
Test No. 15



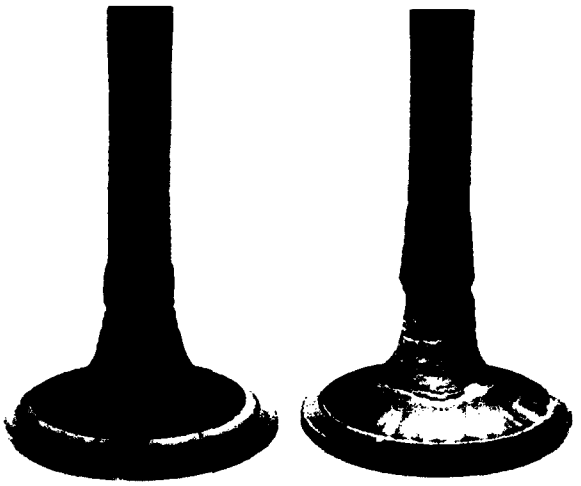
No. 2 - Thrust Side
(Best)

PISTON AND CYLINDER LINER CONDITION
Test No. 15



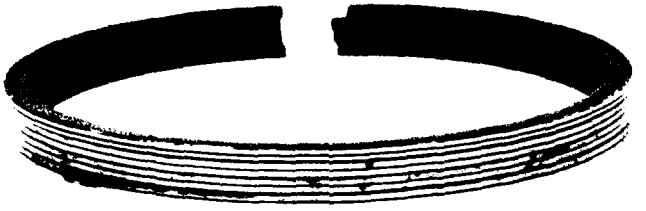
No. 3 - Thrust Side
(Worst)

EXHAUST VALVE DEPOSITS
Test No. 15



RING FACE CONDITION
Test No. 15

Piston - 1



Piston - 2

Piston - 3

APPENDIX C

3-53 TEST # 17

FUEL: 1% S DF-2

LUBE: AL-6739

START: 12 June 1978

END: 30 June 1978

ENGINE OPERATING DATA (AVG)
TEST #17

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2806	2801	650
Load, lb	108	111	109	
Torque, lb-ft	189	194	191	
BHp obs	101	104	102	
Fuel Rate, lb/hr	40.8	45.1	43.2	
BMEP, psi	90	92	90	
BSFC lb/BHp-hr	0.401	0.447	0.424	
Temperatures, °F				
Jacket Coolant-In	195	200	197	
Jacket Coolant-Out	205	205	205	
Oil Sump	238	242	240	100
Inlet Air (Blower)	86	101	94	
Exhaust Manifold	1000	1040	1017	
Fuel @ Return	88	92	90	
Fuel @ Filter	147	154	151	
Pressures				
Oil Gallery, psig	34	36	35	
Blower Discharge, psig	4.3	4.5	4.4	
Intake Vacuum, in. H_2O	6.5	6.7	6.6	
Exhaust, Common, in. Hg	2.1	2.5	2.4	
Avg Oil Consumption, lb/hr (kg/hr)			0.20	(0.09)
Total Oil Consumption lb(kg)			41.9	(19.0)

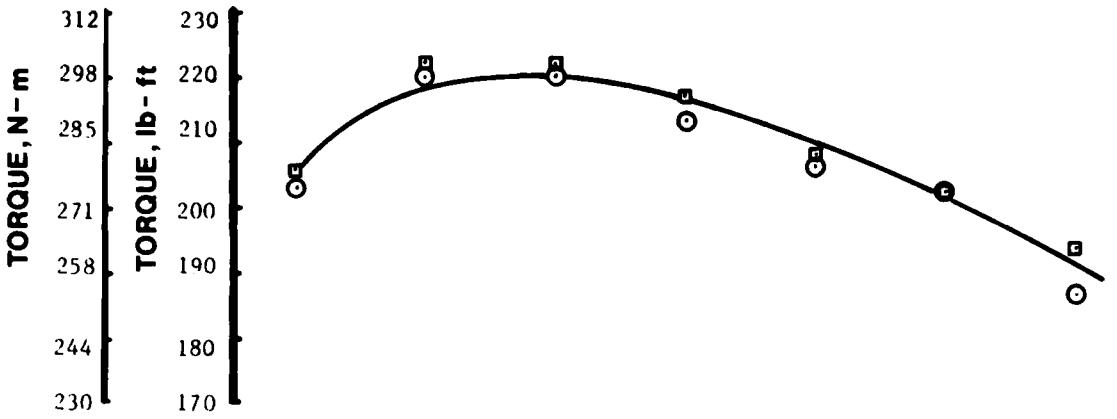
LUBRICANT ANALYSES
TEST #17

Property	Method	New Oil	70 Hr	140 Hr	210 Hr
K. Vis, cS, 40°C	D 445	26.76	30.28	31.37	31.72
K. Vis, cS, 100°C	D 445	5.97	6.66	6.83	6.94
VI	D 2270	179	186	186	189
TAN	D 664	0.3	0.4	0.4	0.5
TBN	D 2896	8.6	4.3	4.8	4.3
Insolubles, wt%	D 893				
Pentane A		A	ND	ND	0.49
Benzene A		A	ND	ND	0.45
Pentane B		A	ND	ND	0.73
Benzene B		A	ND	ND	0.62
API Gravity, °	D 287	21.1	ND	ND	20.0
Flash Point, °C	D 92	249	249	249	246
Carbon Residue, wt%	D 524	1.48	2.03	2.31	2.50
Sulfated Ash, wt%	D 874	1.55	1.78	1.80	1.94
Elemental	Method				
Ba, ppm	AA	0.95	ND	ND	ND
Mg, ppm	AA	<1	ND	ND	ND
Ca, wt%	AA	9	ND	ND	ND
Zn, wt%	AA	4	ND	ND	ND
P, wt%	Mod. oronite	0.01	ND	ND	ND
S, wt%	XRF	0.02	ND	ND	ND
Fe, ppm	AA/XRF	A	40/30	68/57	83/64
Cu, ppm	AA	A	3	4	6
Cr, ppm	AA	A	2	3	5
Pb, ppm	AA	A	6	1	4

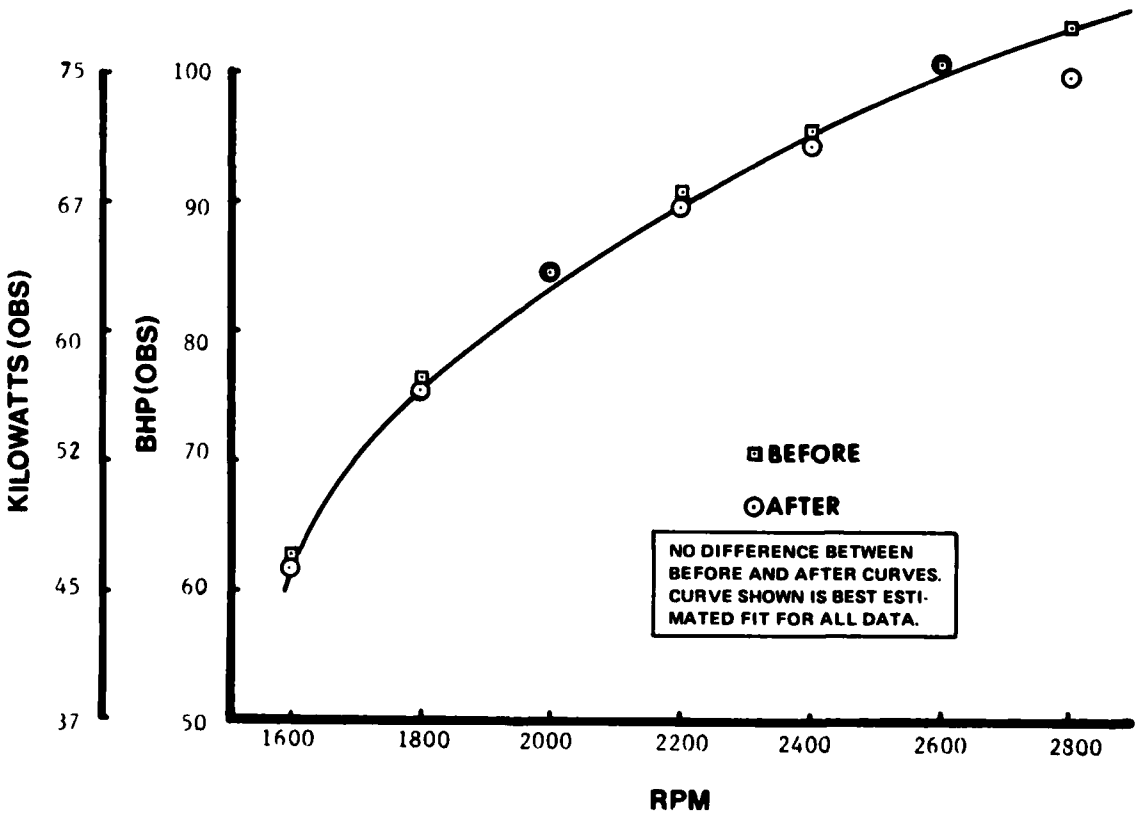
A = Expected to be zero for a new oil.
ND = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

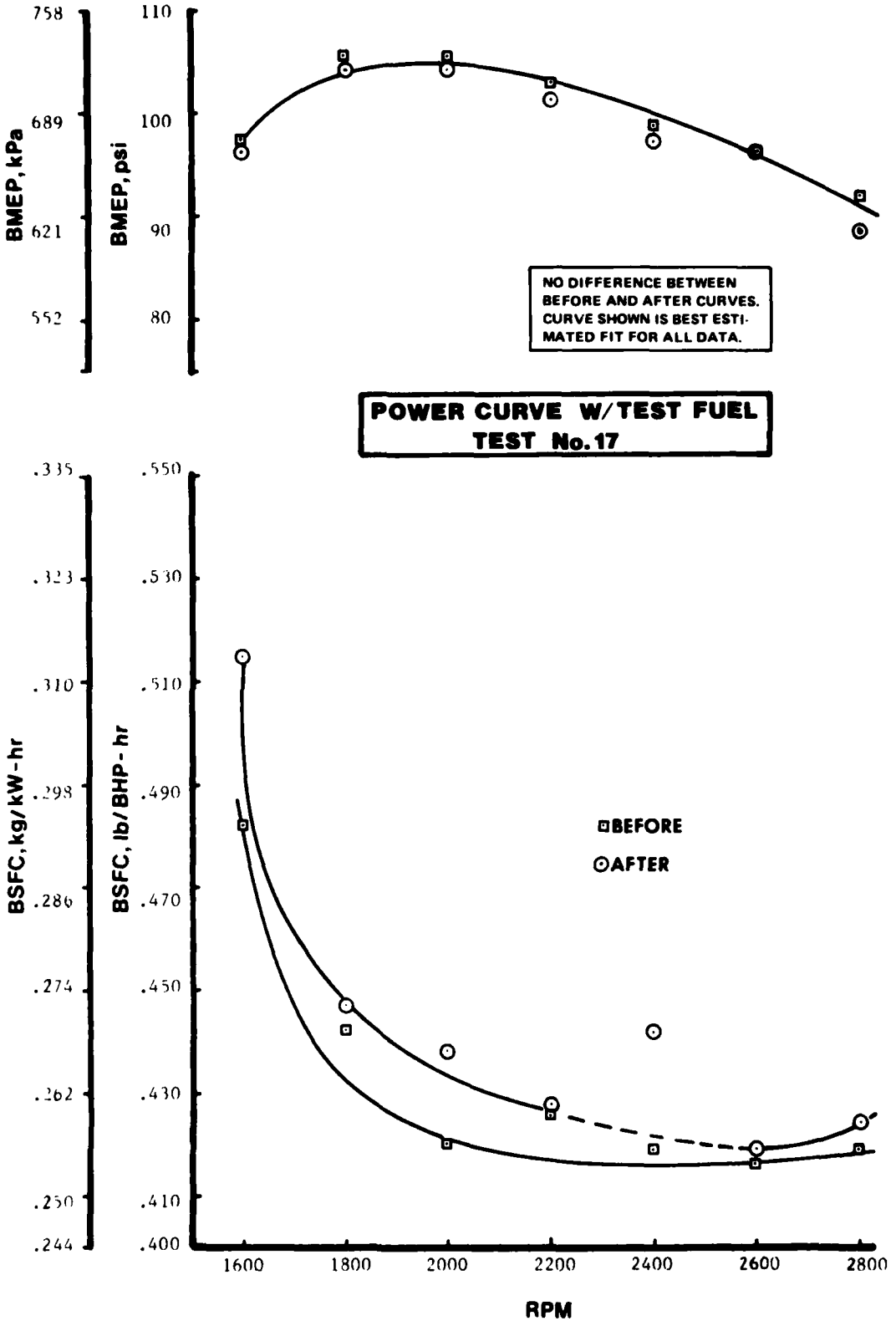
DAILY ANALYSIS OF USED OIL BY XRF

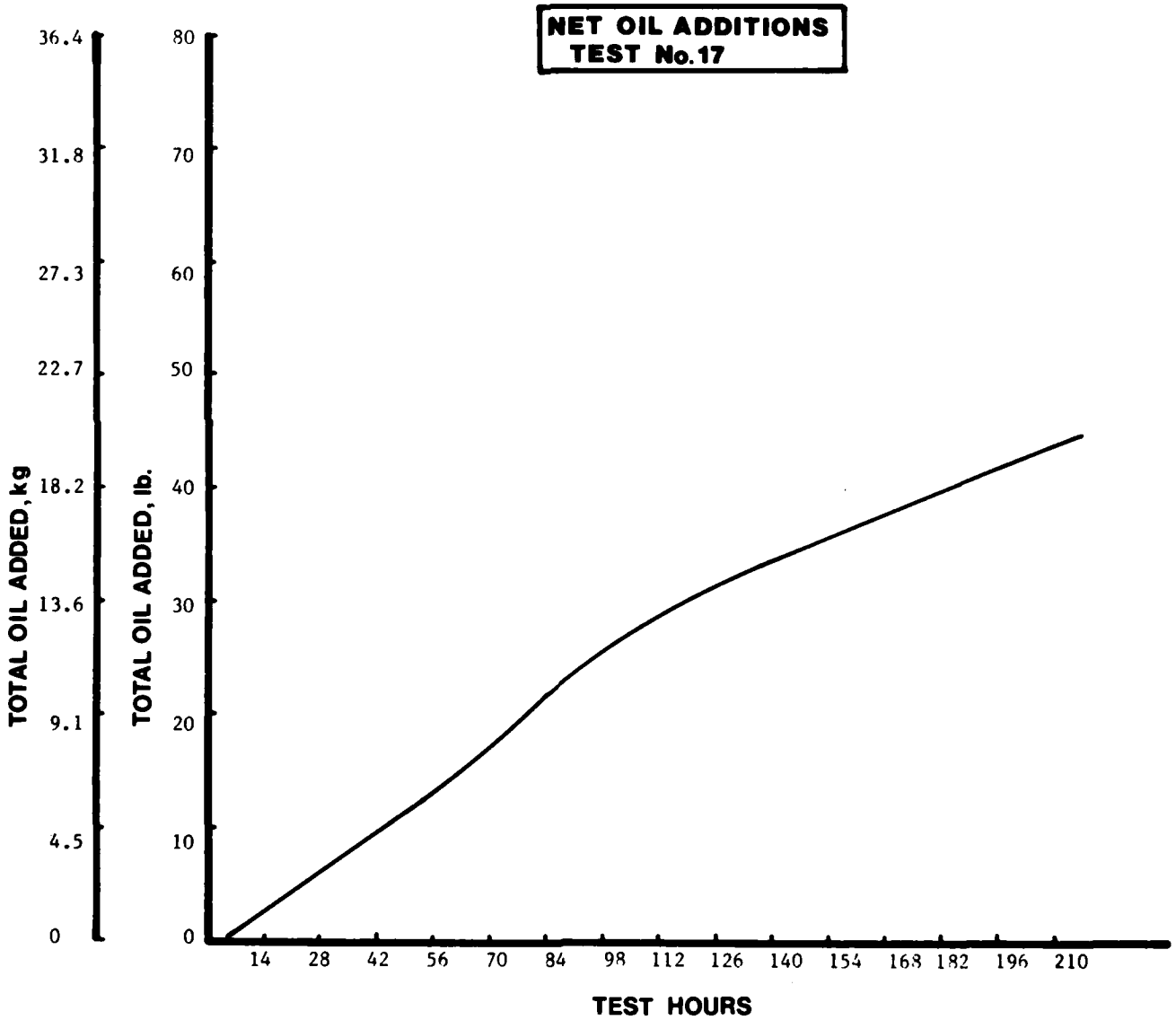
Test Hr	Fe, ppm	Other Elements
14	15	None
28	25	None
42	26	None
56	31	None
70	30	None
84	35	None
98	41	Cu-20 ppm
112	45	Cu- <10 ppm
126	47	None
140	57	None
154	53	None
168	58	None
182	52	None
196	60	None
210	64	None



POWER CURVE W/TEST FUEL
TEST No. 17




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED FIT FOR ALL DATA.
POWER CURVE W/TEST FUEL
TEST No. 17
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No.17
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb.
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #17

	Cylinder Number		
	1	2	3
First Ring	5	5	5
Second Ring	1	< 1	50
Third Ring	2	2	35
Fourth Ring	< 1	N	70

Average of all 15%

N = Normal

RING STICKING
TEST #17

Ring No.	Piston Number		
	1	2	3
1			
2		ALL FREE	
3			
4			

CYLINDER LINERS
TEST #17

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area				
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	5	35	5	20	15	85
2	3	5	5	5	5	95
3	2	5	10	8	15	85
Average	3	15	7	11	12	88

PISTON O.D. (IN)
TEST #17

Cylinder	1	2	3
Before	3.8700	3.8705	3.8705
After	3.8700	3.8705	3.8705
Change	0.0000	0.0000	0.0000

PISTON SURFACE CONDITION
TEST #17

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	ALL LIGHT SCRATCHES		
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #17

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	10
	2	0	0	0
	3	0	0	0
	4	0	0	5
2	1	0	0	0
	2	0	0	0
	3	5	0	90
	4	0	0	5

Quadrants:

1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #17

Area	Cylinder No. 1	2	3
Head	50-AHC to Soot		
Face	8 - Lacquer		
Tulip	9 - Lacquer		
Stem	9 - Lacquer to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #17

	Cylinder No. 1	2	3
Freeness in Guide	All Free		
Head	All Normal		
Face	All Normal		
Seat	All Normal		
Stem	All Normal		
Tip	All Normal		

RING DEPOSITS
TEST #17

Cylinder Number	Piston	1 CARB	1 LACQ	2 CARB	2 LACQ	3 CARB	3 LACQ
Top	1	35-½AHC	65-9	100-½AHC	0	90-½AHC	10-9
	2	0	85-9 15-4	0	95-8 5-2	0	100-6
	3	0	100-3	0	60-6 40-3	0	100-3
	4	0	100-2	0	100-2	0	100-3
ID	1	30-AHC 70-½AHC	0	100-AHC	0	30-AHC 70-½AHC	0
	2	15-AHC 85-½AHC	0	100-½AHC	0	85-AHC	15-9
	3	100-½AHC	0	100-½AHC	0	100-½AHC	0
	4	0	100-9	100-½AHC	0	0	100-9
Bottom	1	0	15-5 85-3	0	5-7 95-3	0	30-5 70-3
	2	0	15-6 85-3	0	80-6 20-2	0	40-6 60-2
	3	0	100-2	0	100-2	0	90-3 10-2
	4	0	100-2	0	50-3 50-2	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6739

RATER E R Lyons DATE 7-6-78
LABORATORY TEST NUMBER 703-17
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1%S DF-2 AL-7475-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	346

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00											10	10.00						
	MHC	0.75	80	60.00	100	75.00	50	37.50			20	15.00	70	52.50						
	MC	0.50							20	10.00										
	LC	0.25	20	5.00			50	12.50	60	15.00	80	20.00	20	5.00						
	VLC	0.15																		
	CARBON RATING		65.00		75.00		50.00		25.00		35.00		67.00							
LACQUER	BL	0.100													100	10.00	50	5.00	100	10.00
	DBrL	0.075																		
	AL	0.050							20	1.00							50	2.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								1.00						10.00		7.50		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			65.00		75.00		50.00		26.00		35.00		67.50		10.00		7.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6739

RATER E R Lyons DATE 7-6-78
LABORATORY TEST NUMBER 703-17
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1%S DF-2 AL-7475-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	395

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00									5	5.00								
	MHC	0.75	25	18.75	100	75.00	100	75.00					100	75.00						
	MC	0.50							60	30.00	95	47.50								
	LC	0.25	75	18.75					40	10.00					45	11.25	25	6.25		
	VLC	0.15																		
	CARBON RATING		37.50		75.00		75.00		40.00		52.50		75.00		11.25		6.25			
LACQUER	BL	0.100													55	5.50	65	6.50	100	10.00
	DBrL	0.075																		
	AL	0.050															10	.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING														5.50		7.00			
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			37.50		75.00		75.00		40.00		52.50		75.00		16.75		13.25		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-6739

RATER E R Lyons DATE 7-6-78
LABORATORY TEST NUMBER 703-17
STAND NO. 2 ENGINE NO. 3D-131703
FUEL 1%S DF-2 AL-7475-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	329

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00			50	50.00	10	10.00					50	50.00	10	10.00				
	MHC	0.75	25	18.75																
	MC	0.50			50	25.00	30	15.00			100	50.00	40	20.00	70	35.00				
	LC	0.25					10	2.50							10	2.50				
	VLC	0.15																		
	CARBON RATING		18.75		75.00		27.50				50.00		70.00		47.50					
LACQUER	BL	0.100	75	7.50			50	5.00	20	2.00			10	1.00	10	1.00	90	9.00	100	10.00
	DBrL	0.075																		
	AL	0.050							80	4.00							10	.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING		7.50				5.00		6.00				1.00		1.00		9.50		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			26.25		75.00		32.50		6.00		50.00		71.00		48.50		9.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN.)
TEST #17

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8762	3.8763	3.8767	3.8773	3.8769	3.8766
	Before	3.8760	3.8763	3.8765	3.8763	3.8763	3.8764
	Δ	0.0002	0.0000	0.0002	0.0010	0.0006	0.0002
2.	After	3.8767	3.8764	3.8767	3.8767	3.8767	3.8767
	Before	3.8764	3.8764	3.8767	3.8761	3.8762	3.8765
	Δ	0.0000	0.0000	0.0000	0.0006	0.0005	0.0002
3.	After	3.8765	3.8765	3.8767	3.8771	3.8775	3.8773
	Before	3.8764	3.8765	3.8767	3.8765	3.8767	3.8767
	Δ	0.0001	0.0000	0.0000	0.0006	0.0008	0.0006

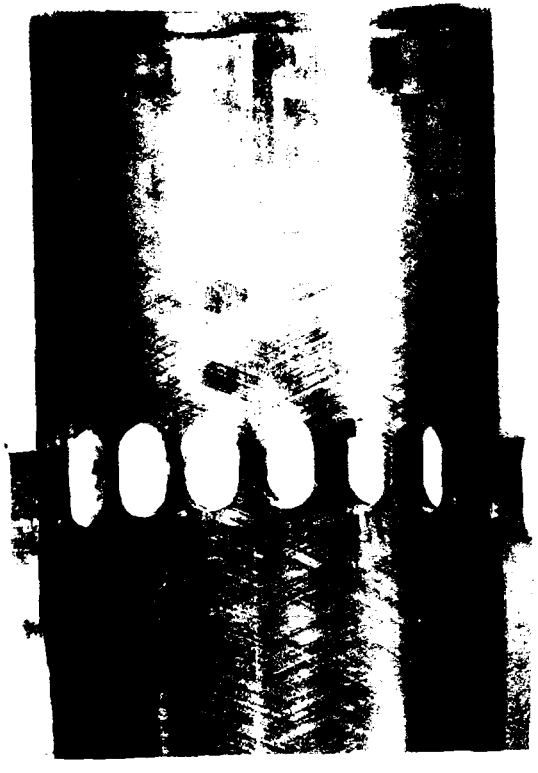
Average (All) 0.0001
Average T/AT 0.0003

PISTON RING GAP (IN.)
TEST #17

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.035	0.029	0.031	0.027	0.021	0.021	0.020	0.021
	Before	0.029	0.029	0.031	0.027	0.019	0.018	0.018	0.018
	Δ	0.006	0.000	0.000	0.000	0.002	0.003	0.002	0.003
2.	After	0.037	0.033	0.030	0.037	0.021	0.020	0.020	0.019
	Before	0.032	0.033	0.030	0.036	0.018	0.019	0.018	0.018
	Δ	0.005	0.000	0.000	0.001	0.003	0.001	0.002	0.001
3.	After	0.032	0.031	0.029	0.025	0.021	0.022	0.021	0.022
	Before	0.028	0.031	0.029	0.025	0.019	0.020	0.019	0.019
	Δ	0.004	0.000	0.000	0.000	0.002	0.002	0.002	0.003

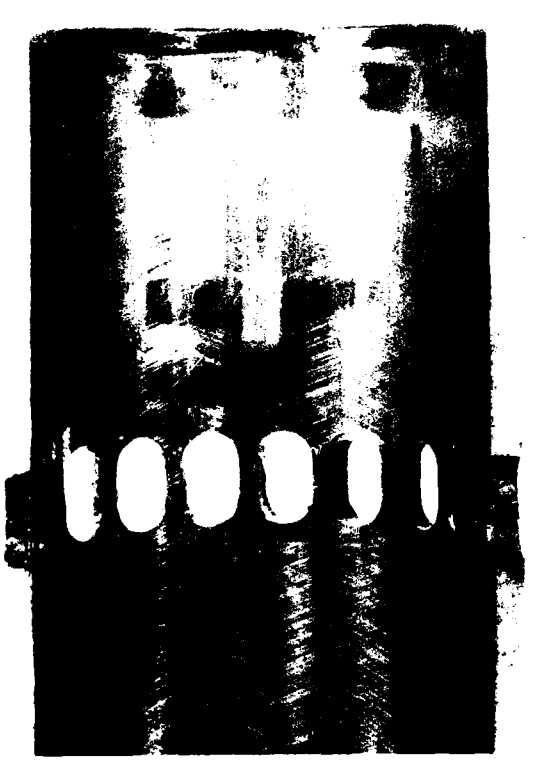
Avg F/R (#1) Wear 0.005

PISTON AND CYLINDER LINER CONDITION
Test No. 17



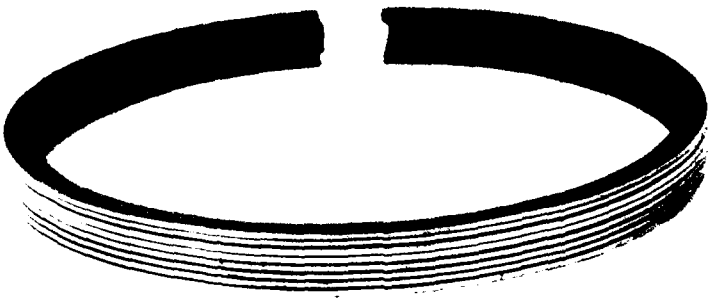
No. 2 - Thrust Side
(Best)

PISTON AND CYLINDER LINER CONDITION
Test No. 17

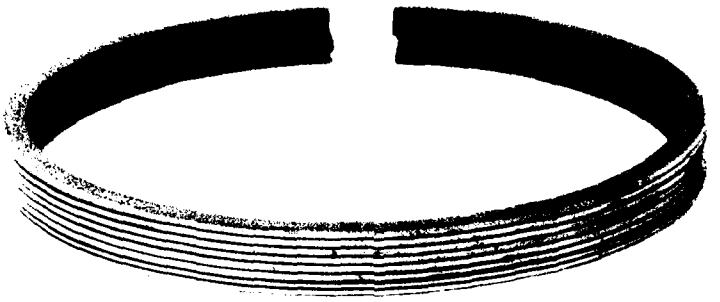


No. 1 - Thrust Side
(Worst)

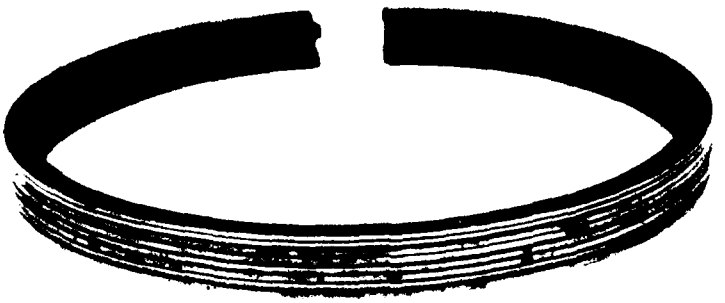
RING FACE CONDITION
Test No. 17



Piston - 1



Piston - 2



Piston - 3

APPENDIX D

3-53 TEST # 19

FUEL: High-Sulfur Fuel (1%S), AL-7766

LUBE: AL-7830

START: 30 November 1978

END: 20 December 1978

ENGINE OPERATING DATA (AVG)
TEST #19

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2795	2810	2802	650
Load, lb	105	109	107	
Torque, lb-ft	184	191	187	
BHp obs	98	102	100	
Fuel Rate, lb/hr	41.7	44.0	42.9	
BMEP, psi	87	90	89	
BSFC lb/BHp-hr	0.417	0.442	0.430	
Temperatures, °F				
Jacket Coolant-In	194	200	197	96
Jacket Coolant-Out	201	206	205	100
Oil Sump	249	256	252	
Inlet Air (Blower)	74	102	87	
Exhaust Manifold	990	1060	1017	
Fuel @ Return	138	150	144	
Fuel @ Filter	80	94	90	
Pressures				
Oil Gallery, psig	42	44	43	
Blower Discharge, psig	4.0	4.4	4.2	
Intake Vacuum, in. H_2O	6.6	6.9	6.7	
Crankcase, in. H_2O	0.48	0.58	0.53	
Exhaust, Common, in. Hg	2.0	2.3	2.2	
Transfer Pump, psig	67	70	70	
Oil Consumption, lb			38.9	

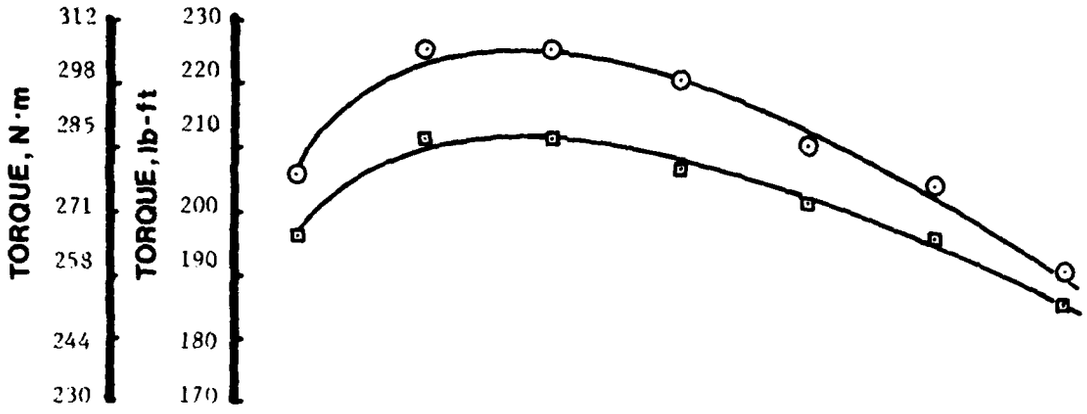
LUBRICANT ANALYSES (AL-7830)
TEST #19

Property	Method	New Oil	70 Hr	140 Hr	210 Hr
K. Vis, cS, 40°C	D445	110.6	121.8	128.9	133.4
K. Vis, cS, 100°C	D445	12.31	12.01	12.53	12.77
VI	D2270	102	86	86	86
TAN	D664	1.7	3.8	3.7	3.5
TBN	D2896	4.8	4.6	4.6	4.4
Insolubles, wt%	D893				
Pentane A		0.02	---	---	0.04
Benzene A		0.02	---	---	0.72
Pentane B		0.03	---	---	0.43
Benzene B		0.02	---	---	0.53
API Gravity, °	D287	27.0	---	---	---
Flash Point, °C	D92	241	---	---	258
Carbon Residue, wt%	D524	1.22	1.62	1.79	1.73
Sulfated Ash, wt%	D874	1.05	---	---	1.23
Elemental	Method				
Ba, ppm	AA	< 5	---	---	---
Mg, ppm	AA	24	---	---	---
Ca, wt%	AA	0.23	0.26	---	0.29
Zn, wt%	AA	0.14	0.16	---	0.18
Cu, ppm	AA	ND	6	8	9
Cr, ppm	AA	ND	4	10	14
Pb, ppm	AA	ND	11	12	13
P, %w	Oronite	0.09	---	---	---
Fe, ppm	AA/XRF	ND	52/65	73/100	81/107

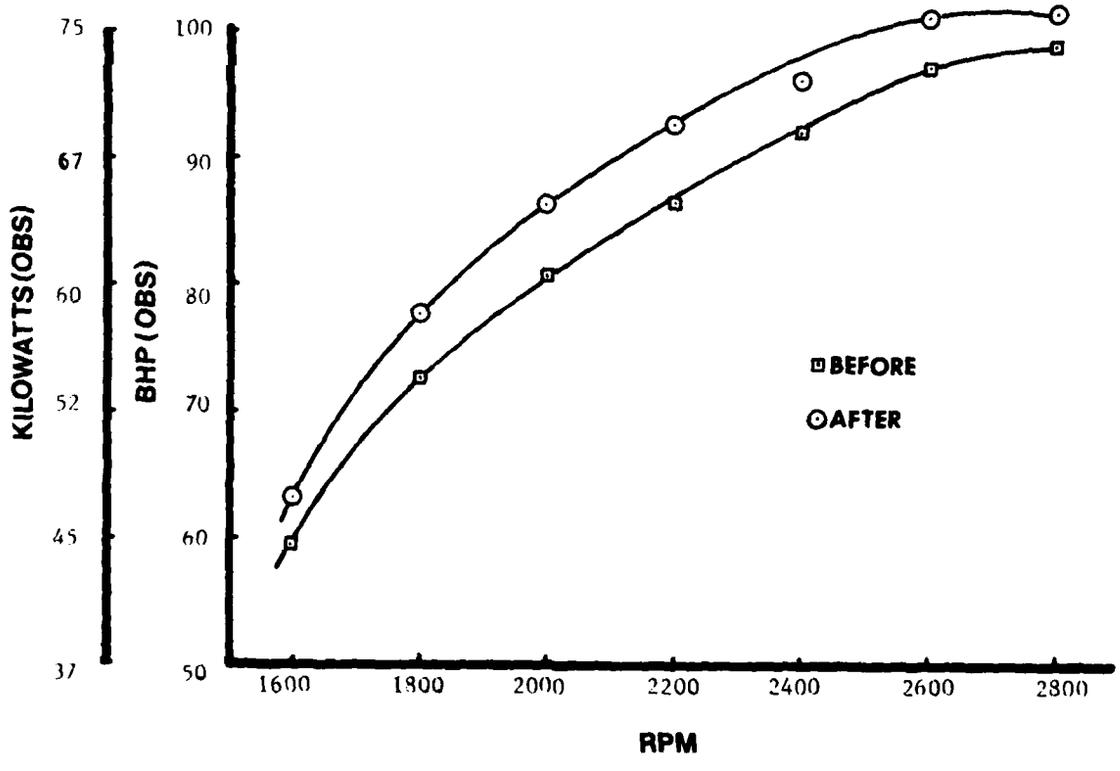
ND = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence

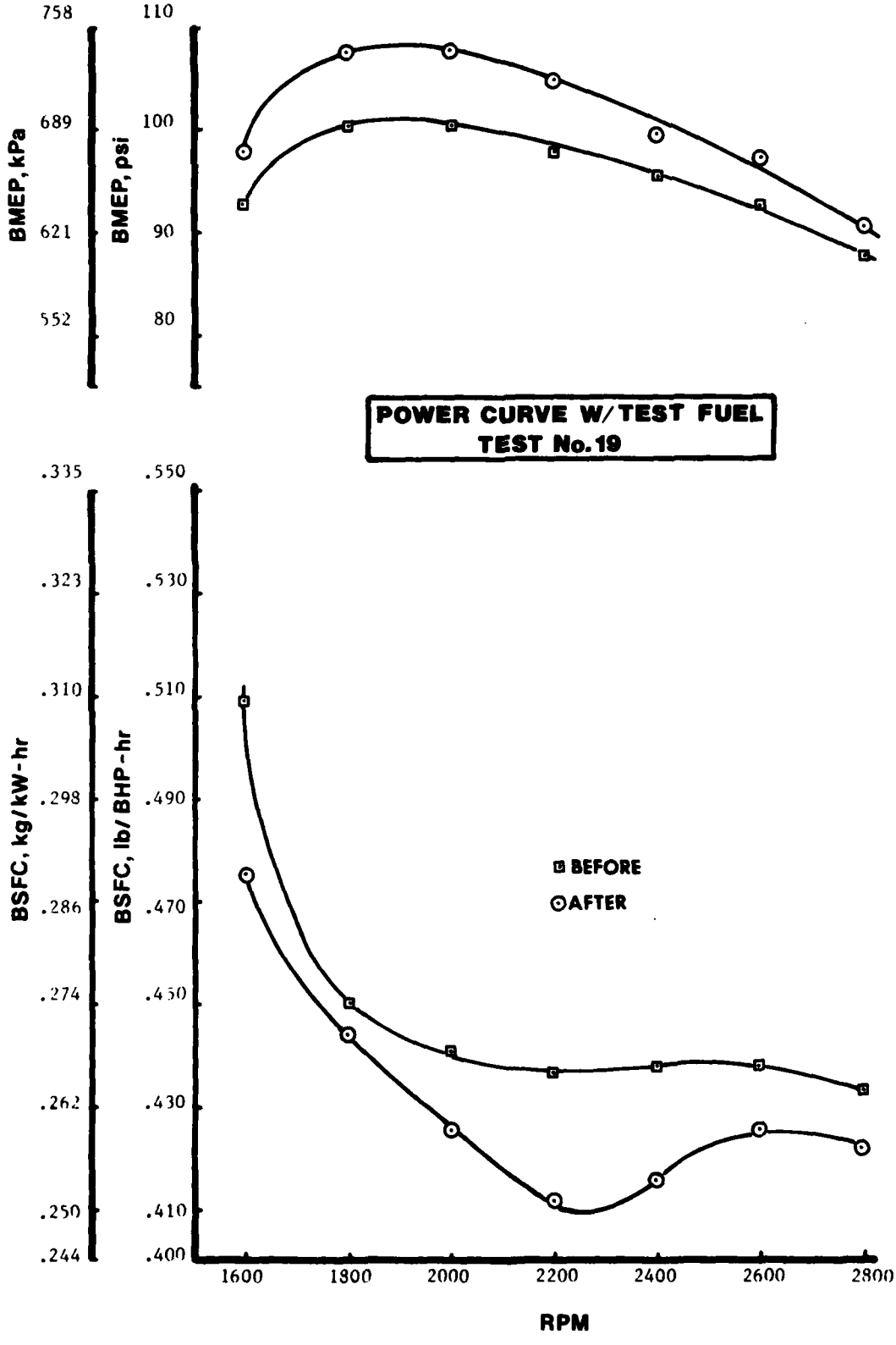
DAILY WEAR METALS BY XRF
TEST #19

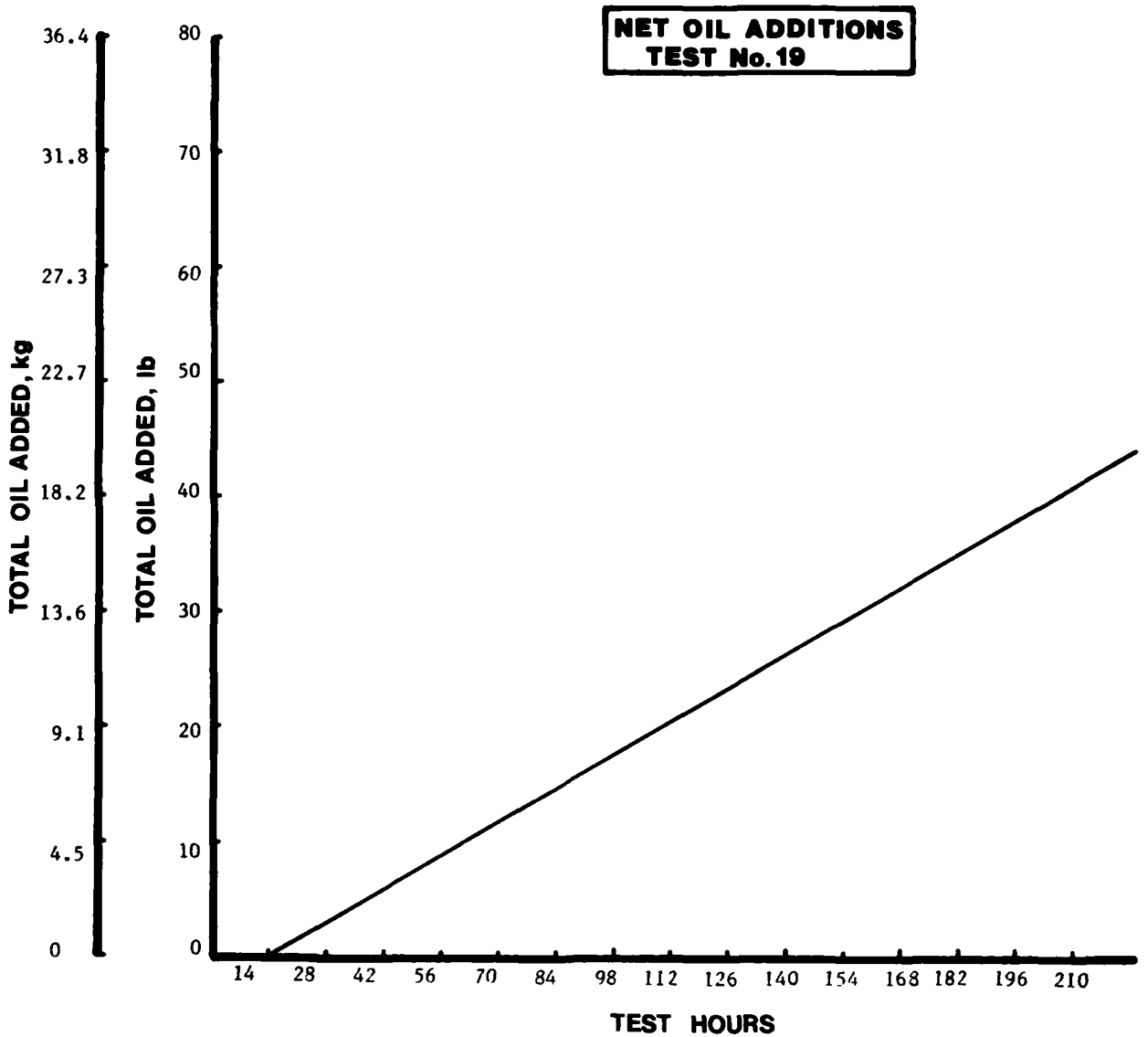
Test Hours	Iron ppm	Other Wear Elements
14	26	None detected
28	45	None detected
42	53	None detected
56	62	None detected
70	65	None detected
84	74	None detected
98	81	None detected
112	89	None detected
126	92	None detected
140	100	None detected
154	99	None detected
168	91	None detected
182	98	None detected
196	110	None detected
210	107	None detected



POWER CURVE W/ TEST FUEL
TEST No. 19




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
POWER CURVE W/TEST FUEL
TEST No.19
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITIONS
TEST No. 19
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #19

	Cylinder Number		
	1	2	3
First Ring	5	2	2
Second Ring	2	25	20
Third Ring	1	25	25
Fourth Ring	5	30	20
Average of all	13.5%		

N = Normal

RING STICKING
TEST #19

Ring No.	Piston Number		
	1	2	3
1	F	F	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #19

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area				
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	5	15	25	20	15	85
2	2	70	80	75	15	85
3	2	10	25	17	15	85
Average	3	32	43	37	15	85

PISTON O.D. (IN)
TEST #19

Cylinder	1	2	3
Before	3.8700	3.8705	3.8700
After	3.8700	3.8700	3.8700
Change	0.0000	0.0005	0.0000

PISTON SURFACE CONDITION
TEST #19

	Piston Number		
	1	2	3
Top Land	ALL NORMAL		
Skirt	ALL LIGHT SCRATCHES		
Piston Pin	ALL NORMAL		

PISTON GROOVE INSIDE DIAMETER - % RING SUPPORTING CARBON
TEST #19

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	5	0
	2	0	25	0
	3	0	25	30
	4	0	0	5
2	1	0	0	95
	2	0	0	100
	3	90	0	0
	4	90	0	0

Quadrants:
1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #19

Area	Cylinder No. 1	2	3
Head	ALL 100% AHC		
Face	ALL 100 - 8 to 9		
Tulip	ALL SOOT		
Stem	ALL 100-9 TO CLEAN		

EXHAUST VALVE SURFACE CONDITIONS
TEST #19

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	N	N	N
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

F = Free
N = Normal

RING DEPOSITS
TEST #19

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	100-½AHC	0	40-AHC	60-9	60-AHC 40-½AHC	0
	2	0	100-5	0	60-7 40-8	0	80-8 20-4
	3	0	15-5 85-4	0	100-5	0	10-7 90-6
	4	0	100-3	0	100-3	0	5-9 95-3
ID	1	50-AHC 50-½AHC	0	100-½AHC	0	100-AHC	0
	2	100-AHC	0	100-AHC	0	100-AHC	0
	3	100-½AHC	0	100-½AHC	0	100-½AHC	0
	4	100-½AHC	0	100-½AHC	0	0	100-9
Bottom	1	0	100-5	0	5-8,90-6 5-7	0	75-7 25-3
	2	0	100-3	0	5-5 95-4	0	5-8 95-7
	3	0	100-4	0	5-9 95-4	0	100-4
	4	0	100-2	0	100-3	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7830

RATER E R Lyons DATE 12-27-78
LABORATORY TEST NUMBER 703-19
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL -7766

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	340

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00			50	50.00							85	85.00						
	MHC	0.75																		
	MC	0.50	90	45.00	30	15.00					80	40.00								
	LC	0.25	10	2.50	20	5.00	100	12.50	50	12.50					85	21.25	75	18.75		
	VLC	0.15									20	3.00	15	2.25						
	CARBON RATING		47.50		70.00		25.00		12.50		43.00		87.25		21.25		18.75			
LACQUER	BL	0.100																	100	10.00
	DBrL	0.075							50	3.75										
	AL	0.050															5	.250		
	LAL	0.025													15	.375	20	.500		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								3.75						.375		.750		10.00	
CLEAN		0																		
ZONAL RATING			47.50		70.00		25.00		16.25		43.00		87.25		21.625		19.500		10.00	
LOCATION FACTOR																				
WEIGHTED RATING																				

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7830

RATER E R Lyons DATE 12-27-78
LABORATORY TEST NUMBER 703-19
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7766

PISTON NO. 2

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	315

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	20	20.00	45	45.00							85	85.00	25	25.00				
	MHC	0.75																		
	MC	0.50	50	25.00	30	15.00					30	15.00								
	LC	0.25	30	7.50	25	6.25	40	10.00			70	17.50	10	2.50	75	18.75				
	VLC	0.15																		
	CARBON RATING		52.50		66.25		10.00				32.50		87.50		43.75					
LACQUER	BL	0.100					60	6.00	10	1.00			5	.500			10	1.00	100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025							90	2.25							90	2.25		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						6.00		3.25				.500				3.25			
CLEAN		0																		
ZONAL RATING			52.50		66.25		16.00		3.25		32.50		88.00		43.75		3.25		10.00	
LOCATION FACTOR																				
WEIGHTED RATING																				

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7830

RATER E R Lyons DATE 12-27-78
LABORATORY TEST NUMBER 703-19
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-7766

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	360

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	10	10.00	50	50.00					5	5.00	80	80.00						
	MHC	0.75																		
	MC	0.50	90	45.00	25	12.50					75	37.50			60	30.00				
	LC	0.25			25	6.25	85	21.25			30	7.50	20	5.00	40	10.00	90	22.50		
	VLC	0.15							25	3.75										
	CARBON RATING		55.00		68.75		21.25		3.75		50.00		85.00		40.00		22.50			
LACQUER	BL	0.100					15	1.50											100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025							75	1.875							10	.250		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING						1.50		1.875								.250		10.00	
CLEAN		0																		
ZONAL RATING			55.00		68.75		22.75		5.265		50.00		85.00		40.00		22.750		10.00	
LOCATION FACTOR																				
WEIGHTED RATING																				

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #19

Cylinder No.		Front/Back Parallel to Crank Top	Middle	Bottom	Thrust/Antithrust Perpendicular to Crank Top	Middle	Bottom
1.	After	3.8759	3.8756	3.8755	3.8778	3.8770	3.8765
	Before	3.8761	3.8758	3.8755	3.8762	3.8760	3.8760
	Change	-0.0002	-0.0002	0.0000	0.0016	0.0010	0.0005
2.	After	3.8760	3.8760	3.8759	3.8780	3.8771	3.8762
	Before	3.8760	3.8760	3.8759	3.8762	3.8759	3.8755
	Change	0.0000	0.0000	0.0000	0.0018	0.0012	0.0007
3.	After	3.8756	3.8757	3.8757	3.8772	3.8770	3.8765
	Before	3.8758	3.8758	3.8757	3.8758	3.8758	3.8758
	Change	-0.0002	-0.0001	0.0000	0.0014	0.0012	0.0007

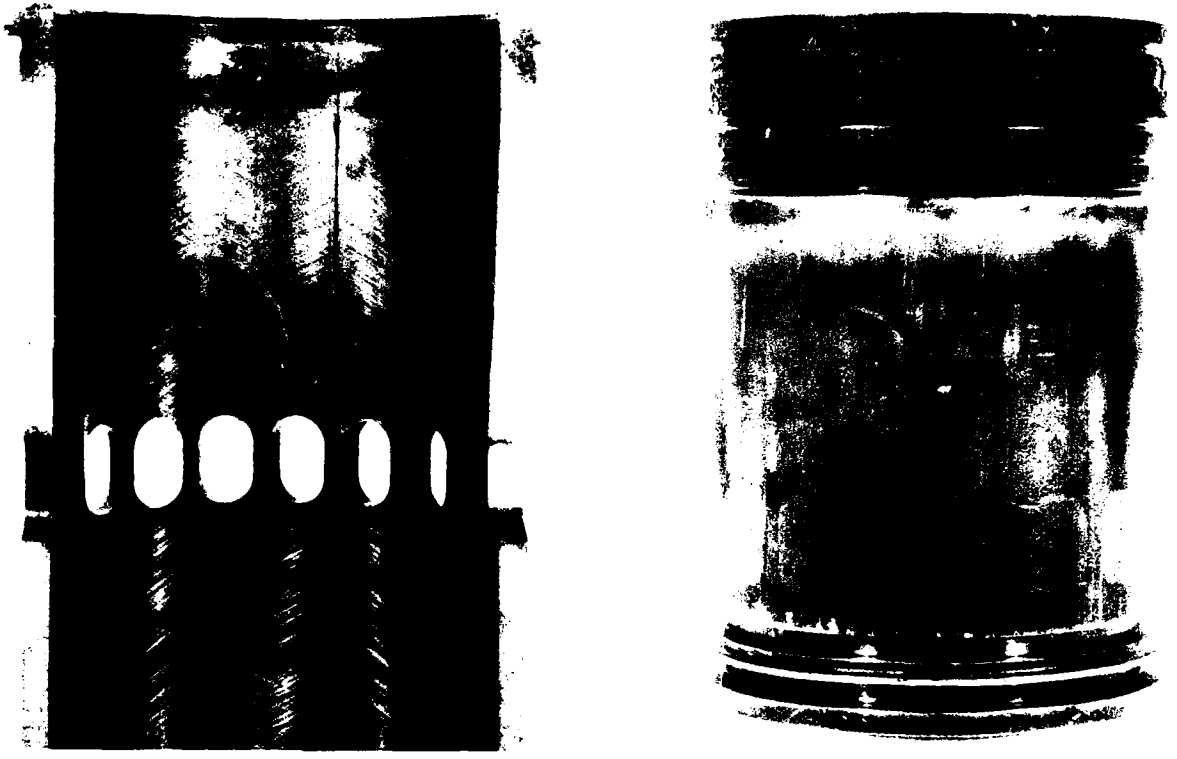
Average (All) 0.0006
Average T/AT 0.0011

PISTON RING GAP (IN)
TEST #19

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.044	0.026	0.036	0.029	0.018	0.018	0.017	0.018
	Before	0.035	0.026	0.036	0.028	0.015	0.015	0.014	0.016
	Change	0.009	0.000	0.000	0.001	0.003	0.003	0.003	0.002
2.	After	0.050	0.028	0.041	0.040	0.017	0.020	0.018	0.018
	Before	0.032	0.028	0.040	0.040	0.014	0.016	0.015	0.015
	Change	0.018	0.000	0.001	0.000	0.003	0.004	0.003	0.003
3.	After	0.050	0.031	0.036	0.036	0.016	0.016	0.015	0.015
	Before	0.032	0.031	0.036	0.036	0.014	0.014	0.014	0.014
	Change	0.018	0.000	0.000	0.000	0.002	0.002	0.001	0.001

Avg F/R (#1) Wear 0.015

PISTON AND CYLINDER LINER CONDITION
Test No. 19

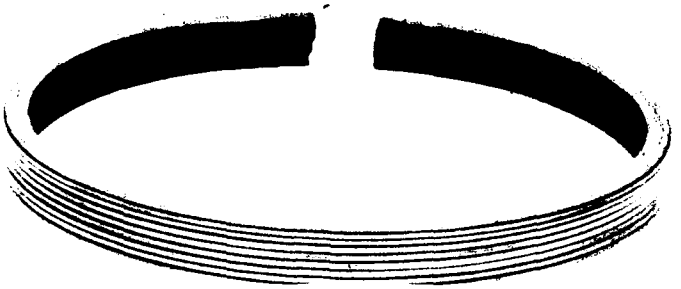


No. 3 - Thrust Side
(Best)

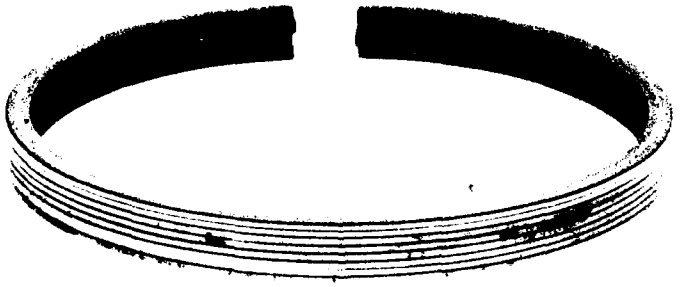
PISTON AND CYLINDER LINER CONDITION
Test No. 19

No. 2 - Antithrust Side
(Worst)

RING FACE CONDITION
Test No. 19



Piston - 1



Piston - 2

Piston - 3

APPENDIX E

3-53 TEST # 20

FUEL: AL-7965-F (1%S)

LUBE: AL-7899-L

START: 22 January 1979

END: 9 February 1979

ENGINE OPERATING DATA (AVG)
TEST #20

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2795	2806	2801	650
Load, lb	109	116	112	
Torque, lb-ft	191	203	195	
BHp obs	102	108	104	
Fuel Rate, lb/hr	41.7	43.9	42.6	
BMEP, psi	90	96	93	
BSFC lb/BHp-hr	0.398	0.424	0.409	
Temperatures, °F				
Jacket Coolant-In	197	199	198	96
Jacket Coolant-Out	204	205	205	100
Oil Sump	234	242	238	
Inlet Air (Blower)	50	92	76	
Exhaust Manifold	940	1000	971	
Fuel @ Return	132	146	141	
Fuel @ Filter	80	99	90	
Pressures				
Oil Gallery, psig	34	36	35	
Blower Discharge, psig	4.1	5.0	4.7	
Intake Vacuum, in. H_2O	6.6	7.2	7.0	
Crankcase, in. H_2O	0.51	0.64	0.55	
Exhaust, Common, in. Hg	2.1	2.8	2.6	
Transfer Pump, psig	69	71	70	

Total Oil Consumption
33.1 lb

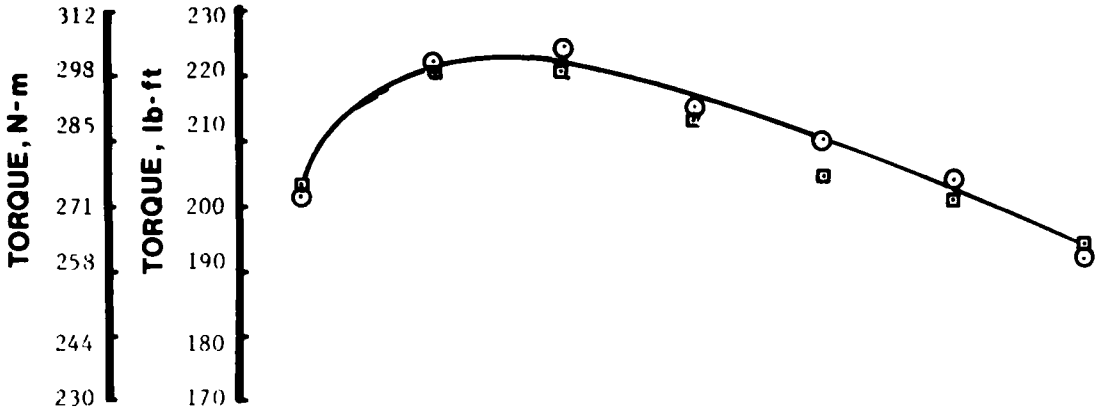
LUBRICANT ANALYSES (AL-7899)
TEST #20

Property	Method	New Oil	70 Hr	140 Hr	210 Hr
K. Vis, cS, 40°C	D 445	27.67	30.14	30.69	31.66
K. Vis, cS, 100°C	D 445	6.08	6.51	6.62	6.77
VI	D 2270	177	178	180	180
TAN	D 664	0.4	0.6	0.7	0.9
TBN	D 2896	6.1	6.8	6.1	5.9
Insolubles, wt%	D 893				
Pentane A		A	ND	ND	0.07
Benzene A		A	ND	ND	0.07
Pentane B		A	ND	ND	0.71
Benzene B		A	ND	ND	0.53
API Gravity, °	D 287	21.1	ND	ND	26.0
Flash Point, °C	D 92	ND	ND	ND	252
Carbon Residue, wt%	D 524	1.10	1.68	2.11	2.34
Sulfated Ash, wt%	D 874	1.55	1.62	1.69	1.75
Elemental	Method				
Ba, ppm	AA	0.93	0.89	ND	0.95
Mg, ppm	AA	<1	1	ND	2
Ca, wt%	AA	<0.01	<0.01	ND	<0.01
Zn, wt%	AA	0.04	0.05	ND	0.05
Cu, ppm	AA	A	3	5	6
Cr, ppm	AA	A	3	7	11
Pb, ppm	AA	A	4	7	10
P, wt%	Oronite	0.01	0.01	0.02	0.02
Fe, ppm	AA/XRF	A	61/53	140/121	209/156

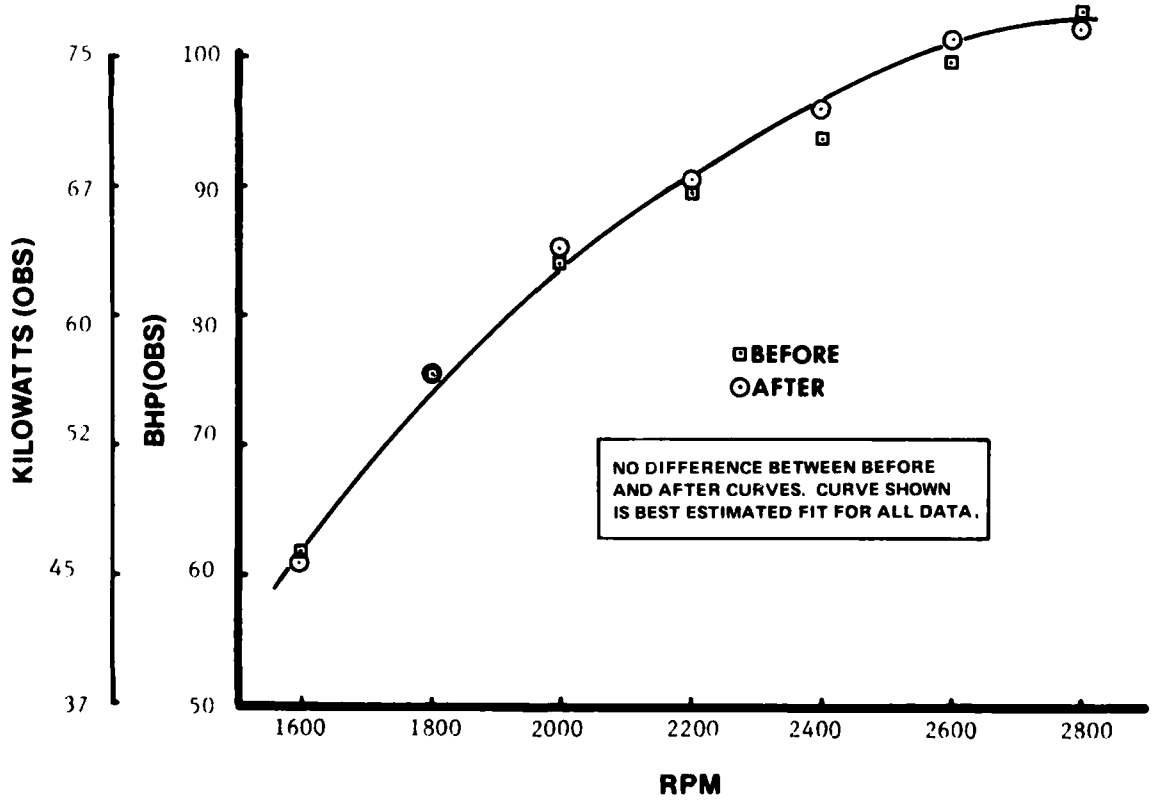
A = Expected to be zero for a new oil.
ND = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

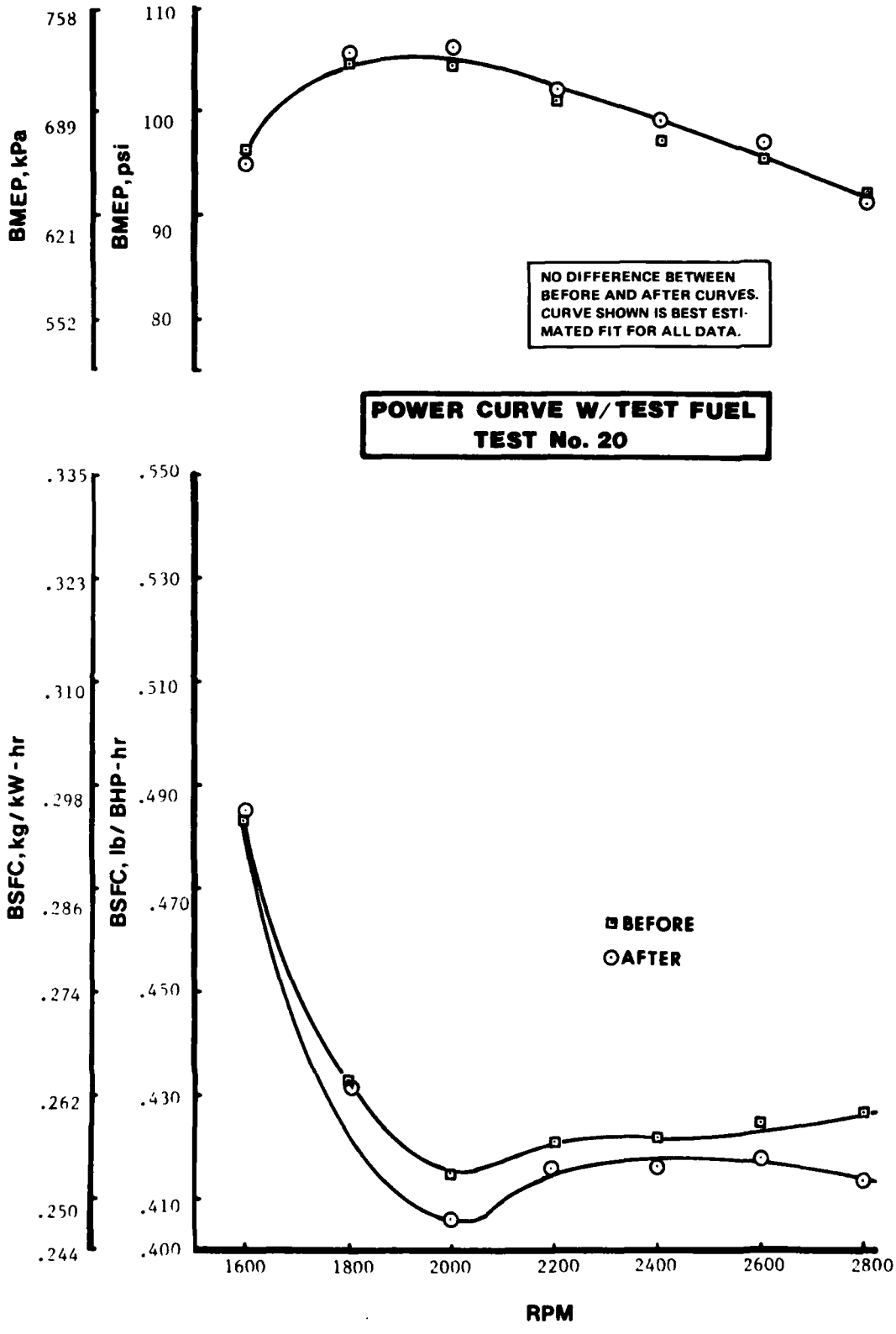
DAILY WEAR METALS BY XRF
TEST #20

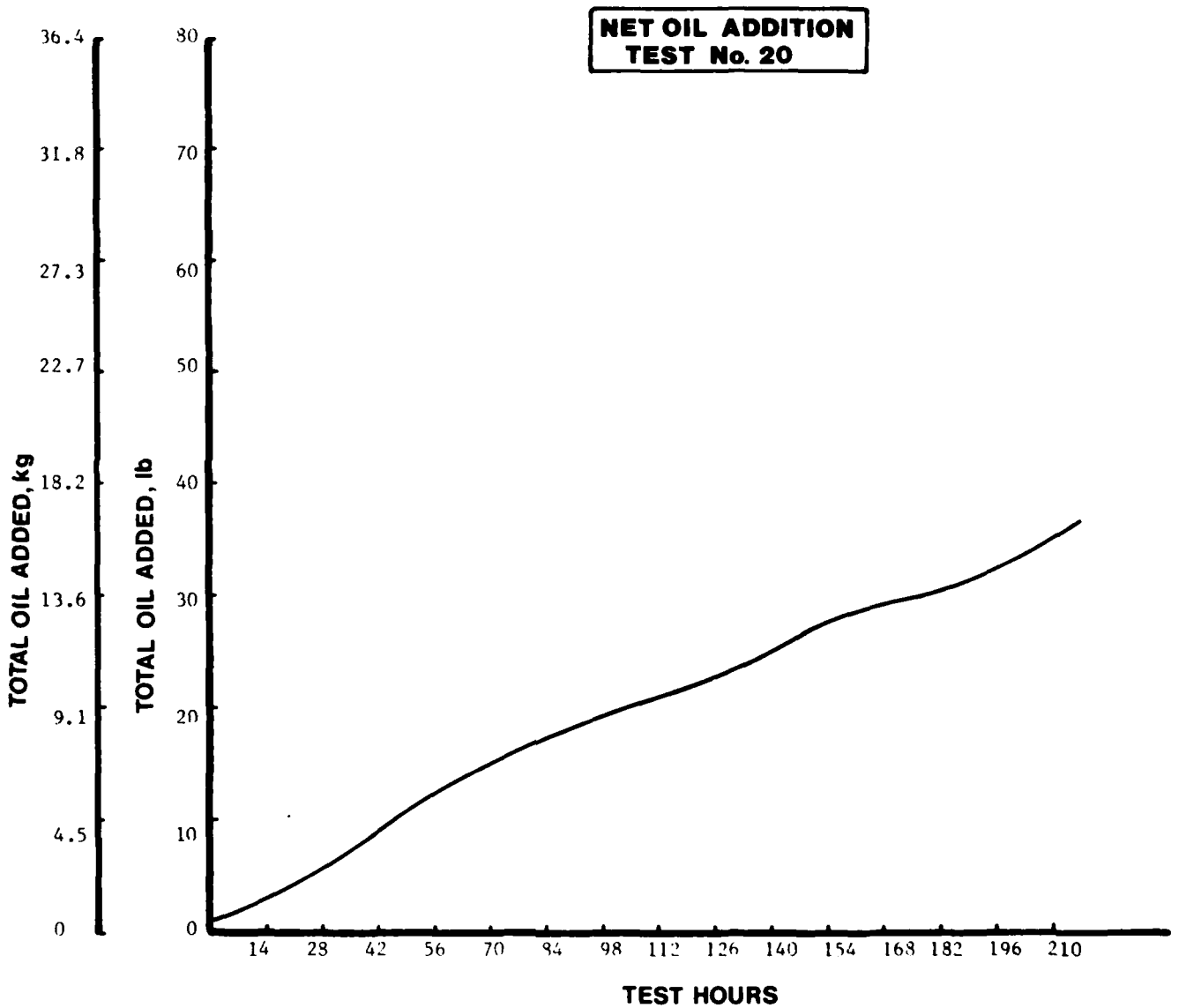
Test Hours	Iron ppm	Other Wear Elements
14	20	None detected
28	26	None detected
42	28	None detected
56	40	None detected
70	53	None detected
84	60	None detected
98	72	None detected
112	93	None detected
126	114	None detected
140	121	None detected
154	114	None detected
168	135	None detected
182	142	None detected
196	151	None detected
210	156	None detected



POWER CURVE W/ TEST FUEL
TEST No. 20




758
689
621
552
BMEP, kPa
110
100
90
80
BMEP, psi
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED FIT FOR ALL DATA.
POWER CURVE W/TEST FUEL
TEST No. 20
.335
.323
.310
.298
.286
.274
.262
.250
.244
BSFC, kg/kW-hr
.550
.530
.510
.490
.470
.450
.430
.410
.400
BSFC, lb/BHP-hr
BEFORE
AFTER
1600
1800
2000
2200
2400
2600
2800
RPM


NET OIL ADDITION
TEST No. 20
TOTAL OIL ADDED, kg
36.4
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
TOTAL OIL ADDED, lb
80
70
60
50
40
30
20
10
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #20

	Cylinder Number		
	1	2	3
First Ring	25	100	20
Second Ring	75	100	45
Third Ring	70	100	45
Fourth Ring	55	100	50
Average of all	65		

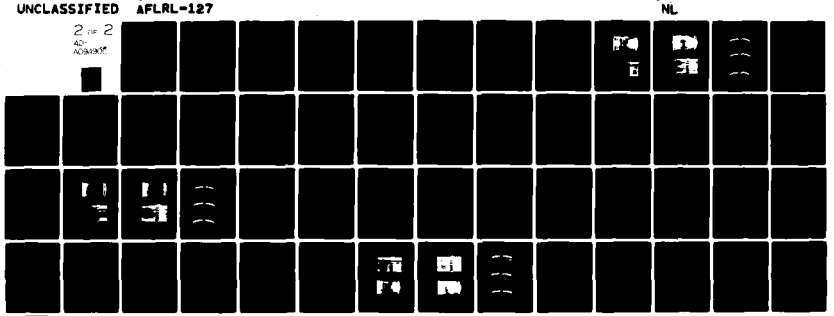
N = Normal

RING STICKING
TEST #20

Ring No.	Piston Number		
	1	2	3
1	F	F	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

AD-A094 900 SOUTHWEST RESEARCH INST SAN ANTONIO TX ARMY FUELS AN--ETC F/G 11/8
LUBRICANTS FOR COMBATING EFFECTS OF HIGH-SULFUR FUEL.(U)
JUL 80 E A FRAME DAAK70-80-C-0001
UNCLASSIFIED AFLRL-127 NL



END
DATE FILMED
3-81
DTIC

CYLINDER LINERS
TEST #20

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area			% Glazed	% Lacquer
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed		
1	10	75	45	60	0	100
2	10	25	75	50	0	100
3	5	20	80	50	1	99
Average	8	40	67	53	0	100

PISTON O.D. (IN)
TEST #20

Cylinder	1	2	3
Before	3.8700	3.8700	3.8700
After	3.8700	3.8700	3.8700
Change	0.0000	0.0000	0.0000

PISTON SURFACE CONDITION
TEST #20

	Piston Number		
	1	2	3
Top Land	N	N	N
Skirt	Lt. Scuffing	Lt. Scratches to Scuff	Lt. Scratches & Scuffing
Piston Pin	N	N	N

N = Normal

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #20

		Piston Number		
Piston Ring	Quadrant	1	2	3
1	1	0	0	0
	2	0	0	0
	3	0	0	15
	4	0	0	0
2	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0

Quadrants:
1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #20

Area	Cylinder No. 1	2	3
Head	Some light soot and 9-Lacq		
Face	100-9 Lacquer to clean		
Tulip	Light Carbon and 9-Lacquer		
Stem	100-9 Lacquer to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #20

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	-Normal to light pitting		
Seat	N	N	N
Stem	-Normal to light wear		
Tip	N	N	N

N = Normal

RING DEPOSITS
TEST #20

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	0	75-8, 10-6 15-5	0	10-6 90-9	10-½AHC	90-9
	2	0	95-9 5-6	0	5-6 95-9	0	100-9
	3	0	100-8	0	15-4 85-8	0	100-7
	4	0	50-6 50-5	0	10-6 90-5	0	25-7 75-5
ID	1	100-½AHC	0	100-½AHC	0	100-½AHC	0
	2	100-½AHC	0	100-½AHC	0	100-½AHC	0
	3	100-½AHC	0	100-½AHC	0	0	100-9
	4	100-½AHC	0	0	100-9	0	100-9
Bottom	1	0	10-8 90-5	0	5-7, 60-3 35-6	0	5-8 15-6 75-7 5-5
	2	0	90-6 10-5	0	15-7 85-6	0	100-4
	3	0	90-4 10-5	0	100-4	0	25-4 75-3
	4	0	100-3	0	100-3	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7899-L

RATER E R Lyons DATE 2-14-79
LABORATORY TEST NUMBER 703-20
STAND NO. 2 ENGINE NO. 703
FUEL AL-7965-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	341

DEPOSIT TYPE	DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON HC	1.00																		
CARBON MHC	0.75			100	75.00							20	15.00						
CARBON MC	0.50	100	50.00			100	50.00	30	15.00			60	30.00			15	7.50		
CARBON LC	0.25							55	13.75	100	25.00	20	5.00	100	25.00	85	21.25		
CARBON VLC	0.15																		
CARBON RATING		50.00		75.00		50.00		28.75		25.00		50.00		25.00		28.75			
LACQUER BL	0.100																		
LACQUER DBrL	0.075																	100	7.50
LACQUER AL	0.050							15	.75										
LACQUER LAL	0.025																		
LACQUER VLAL	0.010																		
LACQUER RL	0.001																		
LACQUER RATING								.75											
CLEAN	0																		
ZONAL RATING																			
LOCATION FACTOR																			
WEIGHTED RATING		50.00		75.00		50.00		29.50		25.00		50.00		25.00		28.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY ALFRL
LUBRICANT AL-7899-L

RATER E R Lyons DATE 2-14-79
LABORATORY TEST NUMBER 703-20
STAND NO. 2 ENGINE NO. 703
FUEL AL-7965-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	369

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			10	10.00							20	20.00	35	35.00				
	MHC	0.75	10	7.50							15	11.25								
	MC	0.50	90	45.00	90	45.00	75	37.50	15	7.50			20	10.00	65	32.50	75	37.50		
	LC	0.25					25	5.25	65	16.25	85	21.25	50	12.50			25	5.25		
	VLC	0.15											10	1.50						
	CARBON RATING		52.50		55.00		42.75		23.75		32.50		44.00		67.50		42.75			
LACQUER	BL	0.100																		
	DBrL	0.075																	100	7.50
	AL	0.050							20	1.00										
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								1.00											
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			52.50		55.00		52.75		24.75		32.50		44.00		67.50		42.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-7899-L

RATER E R Lyons DATE 2-14-79
LABORATORY TEST NUMBER 703-20
STAND NO. 2 ENGINE NO. 703
FUEL AL-7965-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	342

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00			10	10.00	15	15.00					35	35.00	35	35.00	15	15.00		
	MHC	0.75	40	30.00	15	11.25														
	MC	0.50	60	30.00	75	37.50	10	5.00			30	15.00	10	5.00						
	LC	0.25					75	18.75	25	6.25	70	17.25			30	7.50	60	15.00		
	VLC	0.15							65	9.75			55	8.25			25	3.75		
	CARBON RATING		60.00		58.75		38.75		16.00		32.50		48.25		42.50		33.75			
LACQUER	BL	0.100													35	3.50				
	DBrL	0.075																	100	7.50
	AL	0.050							10	.50										
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								.50						3.50				7.50	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			60.00		58.75		38.75		16.50		32.50		48.25		46.00		33.75		7.50	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN.)
TEST #20

Cylinder No.		Front/Back Parallel to Crank			Thrust/Antithrust Perpendicular to Crank		
		Top	Middle	Bottom	Top	Middle	Bottom
1.	After	3.8760	3.8756	3.8754	3.8782	3.8765	3.8759
	Before	3.8759	3.8756	3.8754	3.8760	3.8757	3.8754
	Change	0.0001	0.0000	0.0000	0.0022	0.0008	0.0005
2.	After	3.8775	3.8763	3.8760	3.8776	3.8765	3.8760
	Before	3.8760	3.8759	3.8758	3.8760	3.8757	3.8755
	Change	0.0015	0.0004	0.0002	0.0016	0.0008	0.0005
3.	After	3.8762	3.8756	3.8755	3.8769	3.8760	3.8760
	Before	3.8755	3.8754	3.8754	3.8755	3.8753	3.8753
	Change	0.0007	0.0002	0.0001	0.0014	0.0007	0.0007

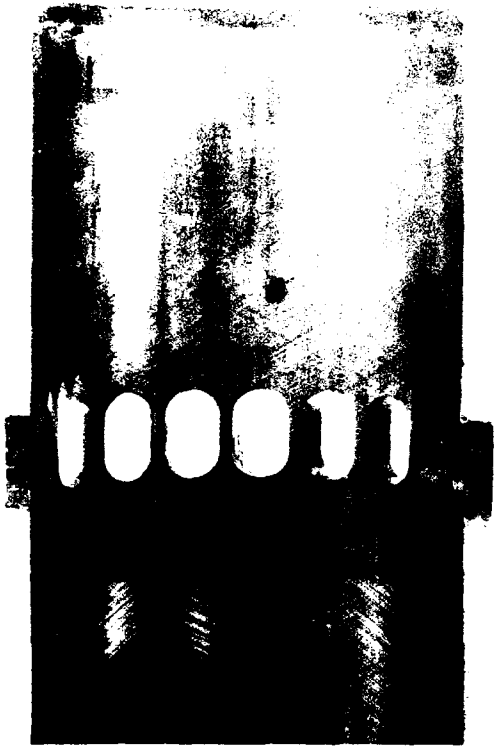
Average (All) 0.0007
Average T/AT 0.0010

PISTON RING GAP (IN.)
TEST #20

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.051	0.028	0.027	0.033	0.019	0.019	0.018	0.018
	Before	0.035	0.028	0.027	0.033	0.016	0.016	0.016	0.014
	Change	0.016	0.000	0.000	0.000	0.003	0.003	0.002	0.004
2.	After	0.046	0.028	0.032	0.031	0.018	0.018	0.018	0.017
	Before	0.033	0.028	0.032	0.031	0.014	0.015	0.014	0.014
	Change	0.013	0.000	0.000	0.000	0.004	0.003	0.004	0.003
3.	After	0.047	0.035	0.036	0.038	0.016	0.016	0.017	0.017
	Before	0.037	0.035	0.036	0.038	0.013	0.013	0.014	0.014
	Change	0.010	0.000	0.000	0.000	0.003	0.003	0.003	0.003

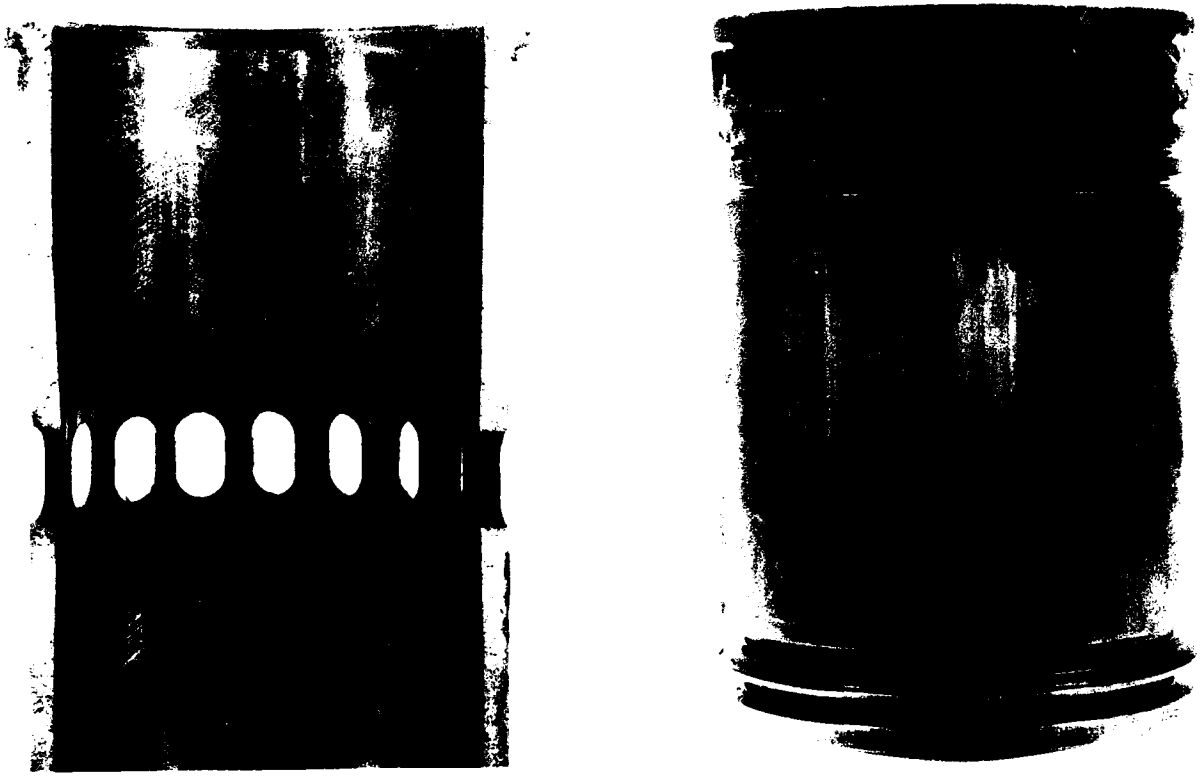
Avg F/R (#1) Wear 0.013

PISTON AND CYLINDER LINER CONDITION
Test No. 20



No. 3 Thrust side
(Best)

PISTON AND CYLINDER LINER CONDITION
Test No. 20

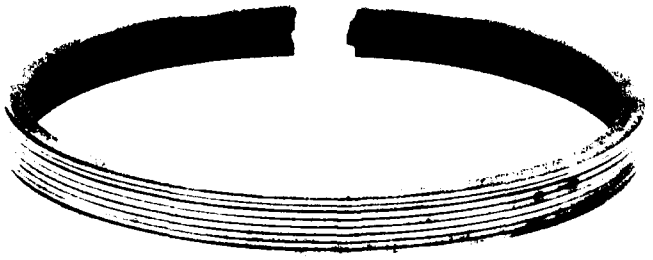


No. 3 Anti-thrust side
(Worst)

RING FACE CONDITION
Test No. 20

Piston - 1

Piston - 2



Piston - 3

APPENDIX F

3-53 TEST # 21

FUEL: AL-7965-F(A) (1%S)

LUBE: AL-8099-L

START: 7 March 1979

END: 27 March 1979

ENGINE OPERATING DATA (AVG)
TEST #21

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2800	2815	2803	652
Load, lb	107	111	109	
Torque, lb-ft	187	194	191	
BHp obs	100	104	102	
Fuel Rate, lb/hr	41.9	44.6	43.0	
BMEP, psi	89	92	91	
BSFC lb/BHp-hr	0.409	0.433	0.422	
Temperatures, °F				
Jacket Coolant-In	190	198	198	96
Jacket Coolant-Out	203	205	205	100
Oil Sump	255	260	258	
Inlet Air (Blower)	86	103	95	
Exhaust Manifold	1000	1050	1025	
Fuel @ Return	139	148	144	
Fuel @ Filter	86	92	89	
Pressures				
Oil Gallery, psig	41	45	44	
Blower Discharge, psig	4.4	4.5	4.5	
Intake Vacuum, in. H_2O	6.5	6.7	6.6	
Crankcase, in. H_2O	0.26	0.31	0.29	
Exhaust, Common, in. Hg	2.2	2.5	2.4	
Transfer Pump, psig	70	74	71	
Oil Consumption				
total lb	53.5			

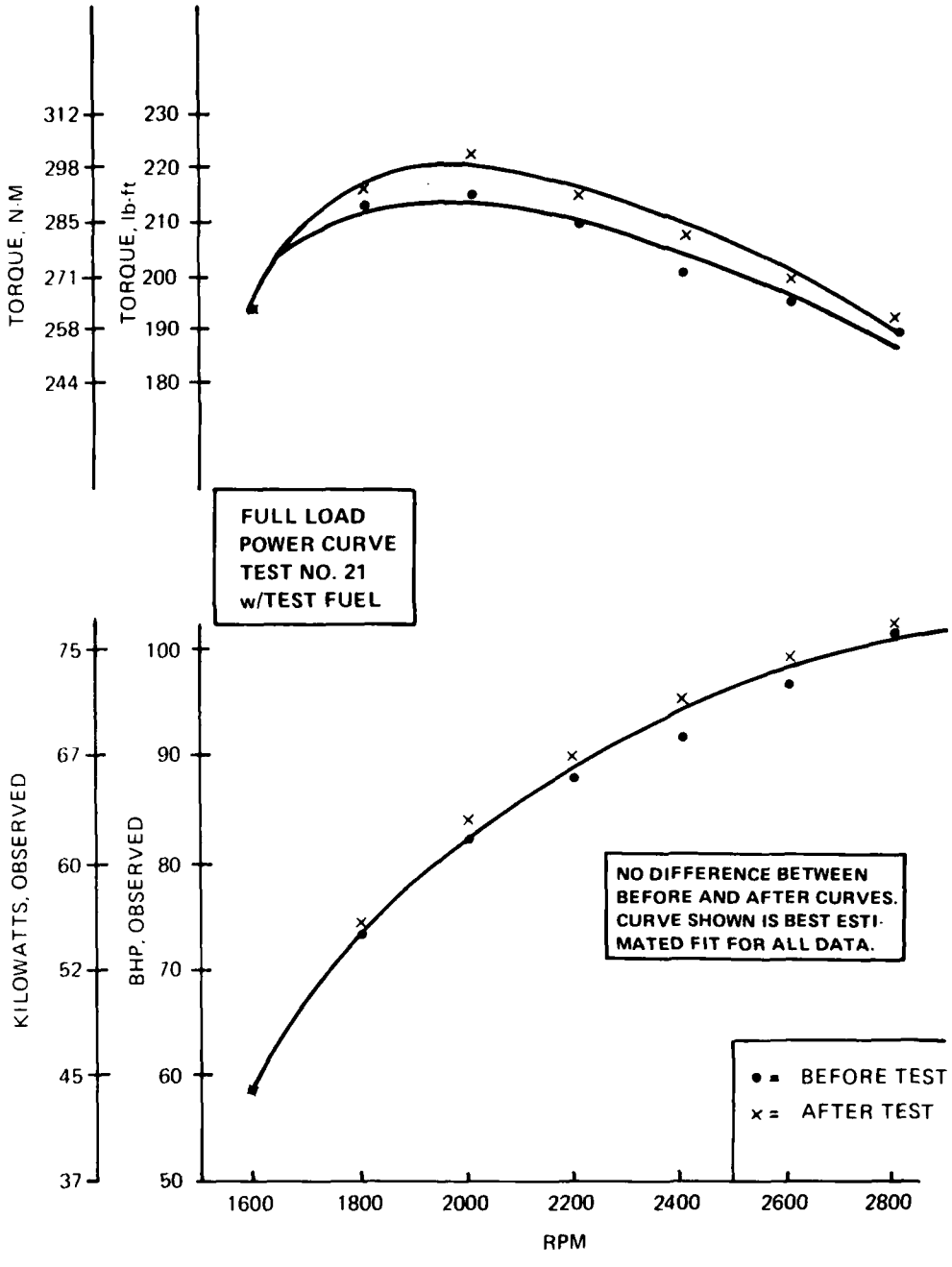
LUBRICANT ANALYSES (AL-8099)
TEST #21

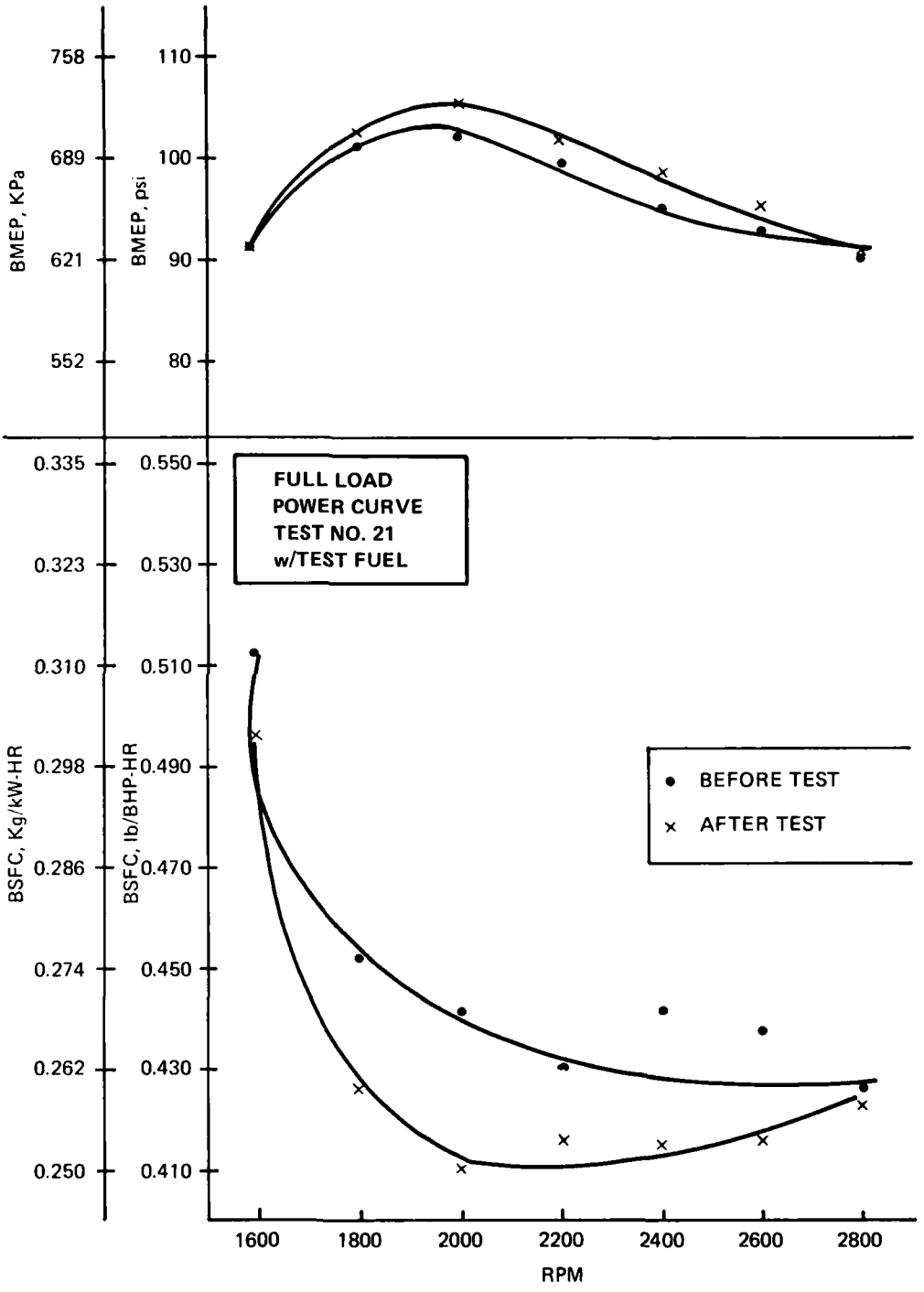
Property	Method	New Oil	70 Hr	140 Hr	210 Hr
K. Vis, cS, 40°C	D 445	110.31	152.74	173.59	180.85
K. Vis, cS, 100°C	D 445	11.64	14.68	15.77	16.52
VI	D 2270	92	95	93	95
TAN	D 664	2.1	3.0	3.4	3.6
TBN	D 2896/	13.0/	12.9/	11.9/	11.9/
	D 664	11.6	5.9	5.3	5.2
Insolubles, wt%	D 893				
Pentane A		A	ND	ND	0.13
Benzene A		A	ND	ND	0.09
Pentane B		A	ND	ND	0.86
Benzene B		A	ND	ND	0.28
API Gravity, °	D 287	25.3	ND	ND	ND
Flash Point, °C	D 92	ND	ND	ND	240
Carbon Residue, wt%	D 524	1.68	2.77	3.17	3.43
Sulfated Ash, wt%	D 874	1.78	ND	ND	2.06
Elemental	Method				
Ca, wt%	AA	0.48	ND	ND	ND
Zn, wt%	AA	0.13	0.12	0.13	0.13
Cu, ppm	AA	A	4	6	7
Cr, ppm	AA	A	1	2	2
Pb, ppm	AA	A	7	8	8
Fe, ppm	AA/XRF	A	42/33	58/46	72/56

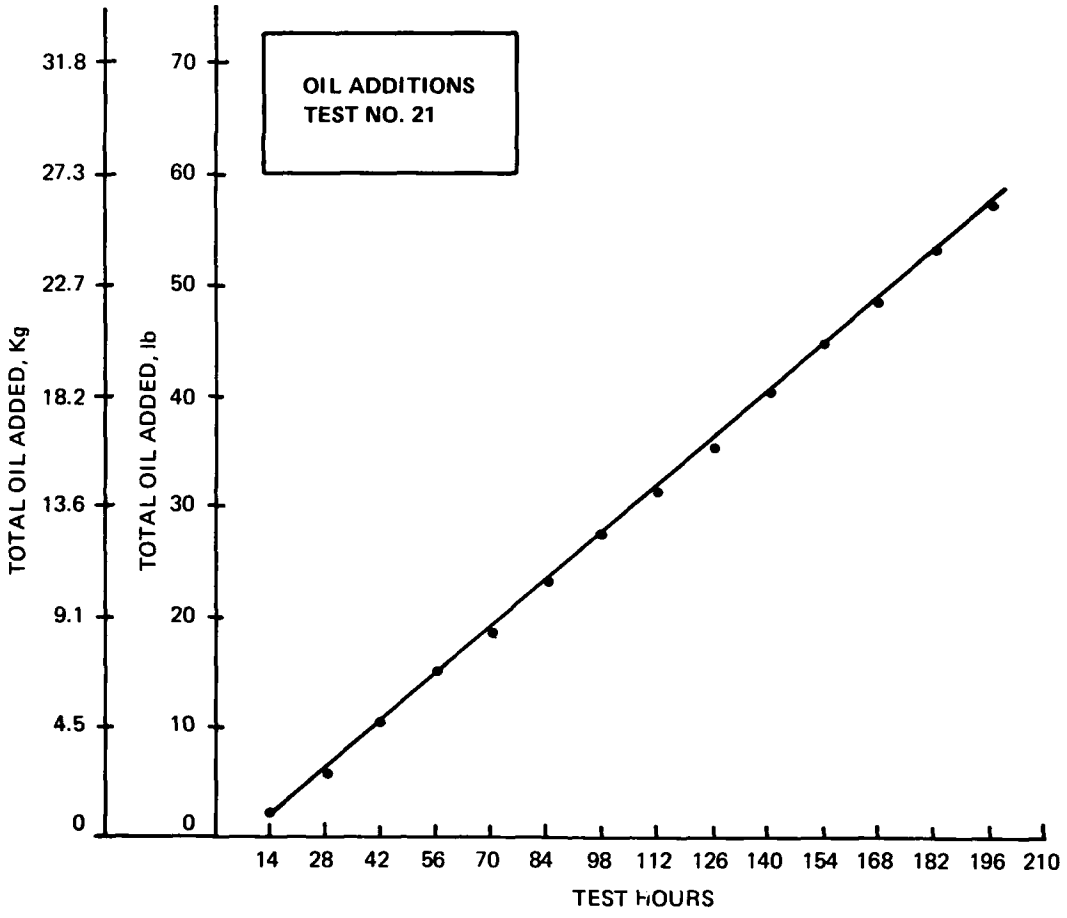
A = Expected to be zero for a new oil.
ND = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

DAILY WEAR METALS BY XRF
TEST #21

Test Hours	Iron ppm	Other Wear Elements
14	16	None detected
28	28	None detected
42	33	None detected
56	40	None detected
70	42	None detected
84	56	None detected
98	51	None detected
112	57	None detected
126	58	None detected
140	58	None detected
154	58	None detected
168	56	None detected
182	63	None detected
196	65	None detected
210	72	None detected


TORQUE, N·M
312
298
285
271
258
244
TORQUE, lb-ft
230
220
210
200
190
180
FULL LOAD
POWER CURVE
TEST NO. 21
w/TEST FUEL
KILOWATTS, OBSERVED
75
67
60
52
45
37
BHP, OBSERVED
100
90
80
70
60
50
NO DIFFERENCE BETWEEN
BEFORE AND AFTER CURVES.
CURVE SHOWN IS BEST ESTI-
MATED FIT FOR ALL DATA.
• = BEFORE TEST
× = AFTER TEST
1600
1800
2000
2200
2400
2600
2800
RPM


758
689
621
552
BMEP, KPa
110
100
90
80
BMEP, psi
FULL LOAD
POWER CURVE
TEST NO. 21
w/TEST FUEL
0.335
0.323
0.310
0.298
0.286
0.274
0.262
0.250
BSFC, Kg/kW-HR
0.550
0.530
0.510
0.490
0.470
0.450
0.430
0.410
BSFC, lb/BHP-HR
BEFORE TEST
AFTER TEST
1600
1800
2000
2200
2400
2600
2800
RPM


OIL ADDITIONS
TEST NO. 21
TOTAL OIL ADDED, Kg
TOTAL OIL ADDED, lb
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
70
60
50
40
30
20
10
0
14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #21

	Cylinder Number		
	1	2	3
First Ring	50	25	5
Second Ring	50	90	N
Third Ring	80	85	N
Fourth Ring	85	70	N
Average of all	45		

N = Normal

RING STICKING
TEST #21

Ring No.	Piston Number		
	1	2	3
1	50% Cold Stuck	100% Cold Stuck	100% Cold Stuck
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #21

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area				
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	2	75	25	50	25	75
2	2	20	50	35	15	85
3	3	5	5	5	5	95
Average	3	33	27	30	15	85

PISTON O.D. (IN)
TEST #21

Cylinder	1	2	3
Before	3.8705	3.8710	3.8705
After	3.8705	3.8710	3.8705
Change	0.0000	0.0000	0.0000

PISTON SURFACE CONDITION
TEST #21

	Piston Number		
	1	2	3
Top Land	Normal	Normal	Normal
Skirt	Lt. Scratches	Lt Scratches	Med Scuff-Thrust side
Piston Pin	Normal	Normal	Normal

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #21

		Piston Number		
Piston Ring	Quadrant	1	2	3
1	1	95	15	100
	2	0	0	5
	3	0	0	5
	4	0	0	15
2	1	0	80	50
	2	0	0	0
	3	95	80	100
	4	40	70	100

Quadrants:
1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #21

Area	Cylinder No. 1	2	3
Head	All - AHC to soot		
Face	All - 100% - 9 Lacquer to clean		
Tulip	All - AHC to soot		
Stem	All - 9 Lacquer to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #21

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	N	N	N
Seat	N	N	N
Stem	N	N	N
Tip	N	N	Lt Wear

F = Free
N = Normal

RING DEPOSITS
TEST #21

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	LACQ
Top	1	100-AHC	0	100-AHC	0	20-AHC 80-½ AHC	0
	2	0	30-8 70-7	0	20-8 80-6	0	15-9 60-6 25-8
	3	0	100-5	0	100-5	0	100-6
	4	0	100-4	0	100-3	0	100-5
ID	1	100-AHC	0	100-AHC	0	100-AHC	0
	2	100-AHC	0	100-AHC	0	100-AHC	0
	3	100-½ AHC	0	100-½ AHC	0	100-AHC	0
	4	0	100-9	0	100-9	0	100-9
Bottom	1	0	10-8 30-6 60-4	0	100-3	0	100-2
	2	0	10-6 90-3	0	5-8 95-3	0 0	5-8 70-3 25-5
	3	0	10-7 90-4	0	25-7 75-5	0	50-6 50-2
	4	0	25-4 75-3	0	100-3	0	100-3

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8099-L

RATER E R Lyons DATE 4-2-79
LABORATORY TEST NUMBER 21
STAND NO. 2 ENGINE NO. 353-703
FUEL AL-7965-F

PISTON NO. 1

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	475

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1		GROOVES NO. 2		GROOVES NO. 3		GROOVES NO. 4		LANDS NO. 1		LANDS NO. 2		LANDS NO. 3		LANDS NO. 4		UNDER-CROWN	
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00	30	30.00	75	75.00	15	15.00	10	10.00	100	100.00	90	90.00						
CARBON	MHC	0.75													75	56.25				
CARBON	MC	0.50	70	35.00	25	12.50	10	5.00												
CARBON	LC	0.25											10	2.50	25	6.25	50	12.50		
CARBON	VLC	0.15																		
CARBON	CARBON RATING		65.00		87.50		20.00		10.00		100.00		92.50		62.50		12.50			
LACQUER	BL	0.100					75	7.50									10	1.00	100	10.00
LACQUER	DBrL	0.075																		
LACQUER	AL	0.050							90	4.50							40	2.00		
LACQUER	LAL	0.025																		
LACQUER	VLAL	0.010																		
LACQUER	RL	0.001																		
LACQUER	LACQUER RATING						7.50		4.50								3.00		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			65.00		87.50		27.50		14.50		100.00		92.50		62.50		15.50		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8099-L

RATER E.R. Lyons DATE 4-2-79
LABORATORY TEST NUMBER 21
STAND NO. 2 ENGINE NO. 353-703
FUEL AL-7965-F

PISTON NO. 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	482

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	50	50.00	100	100.00	15	15.00			80	80.00	75	75.00						
	MHC	0.75													100	75.00				
	MC	0.50					5	2.50	5	2.50										
	LC	0.25	50	12.50			80	20.00			20	5.00	25	6.25			90	22.50		
	VLC	0.15							5	.75										
	CARBON RATING		62.50		100.00		37.50		3.25		85.00		81.25		75.00		22.50			
LACQUER	BL	0.100																	100	10.00
	DBrL	0.075																		
	AL	0.050							90	4.50							10	.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								4.50								.50		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			62.50		100.00		37.50		7.75		85.00		81.25		75.00		23.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8099-L

RATER E R Lyons DATE 4-2-79
LABORATORY TEST NUMBER 21
STAND NO. 2 ENGINE NO. 703-53
FUEL AL-7965-F

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	500

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00	100	100.00	100	100.00	10	10.00			80	80.00	80	80.00	10	10.00				
	MHC	0.75																		
	MC	0.50					70	35.00							90	45.00				
	LC	0.25					20	5.00			20	5.00	20	5.00			10	2.50		
	VLC	0.15							25	3.75										
	CARBON RATING		100.00		100.00		50.00		3.75		85.00		85.00		55.00		2.50			
LACQUER	BL	0.100															20	2.00	100	10.00
	DBrL	0.075																		
	AL	0.050							75	3.75							70	3.50		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								3.75								5.50		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			100.00		100.00		50.00		7.50		85.00		85.00		55.00		8.00		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #21

Cylinder No.		Front/Back Parallel to Crank Top	Front/Back Parallel to Crank Middle	Front/Back Parallel to Crank Bottom	Thrust/Antithrust Perpendicular to Crank Top	Thrust/Antithrust Perpendicular to Crank Middle	Thrust/Antithrust Perpendicular to Crank Bottom
1.	After	3.8764	3.8762	3.8766	3.8762	3.8768	3.8763
	Before	3.8765	3.8764	3.8765	3.8756	3.8960	3.8762
	Change	(0.0001)	(0.0002)	0.0001	0.0006	0.0008	0.0002
2.	After	3.8762	3.8762	3.8766	3.8763	3.8768	3.8762
	Before	3.8760	3.8762	3.8765	3.8760	3.8760	3.8761
	Change	0.0002	0.0000	0.0001	0.0003	0.0008	0.0001
3.	After	3.8755	3.8756	3.8760	3.8766	3.8762	3.8764
	Before	3.8757	3.8758	3.8758	3.8759	3.8758	3.8760
	Change	(0.0002)	(0.0002)	0.0002	0.0007	0.0004	0.0004

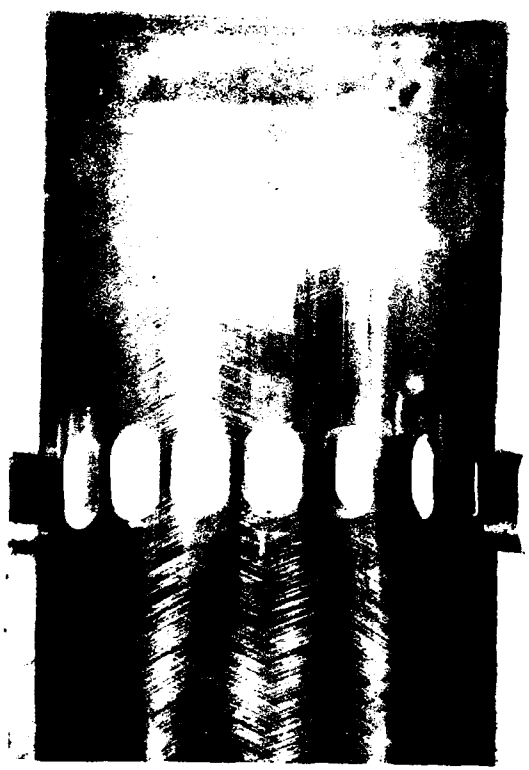
Average (All) 0.0004
Average T/AT 0.0005

PISTON RING GAP (IN)
TEST #21

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.035	0.035	0.036	0.030	0.024	0.022	0.022	0.022
	Before	0.031	0.034	0.036	0.030	0.020	0.020	0.019	0.019
	Change	0.004	0.001	0.000	0.000	0.004	0.002	0.003	0.003
2.	After	0.035	0.035	0.034	0.035	0.022	0.024	0.022	0.022
	Before	0.032	0.035	0.033	0.033	0.018	0.018	0.018	0.019
	Change	0.003	0.000	0.001	0.002	0.004	0.006	0.004	0.003
3.	After	0.033	0.035	0.035	0.030	0.025	0.025	0.024	0.024
	Before	0.031	0.035	0.035	0.030	0.019	0.019	0.019	0.019
	Change	0.002	0.000	0.000	0.000	0.006	0.006	0.005	0.005

Avg F/R (#1) Wear 0.003

PISTON AND CYLINDER LINER CONDITION
Test No. 21



No. 3 - Thrust Side
(Best)

PISTON AND CYLINDER LINER CONDITION
Test No. 21

No. 1 - Thrust Side
(Worst)

RING FACE CONDITION
Test No. 21

Piston - 1

Piston - 2

Piston - 3

APPENDIX G

3-53 TEST # 23

FUEL: AL-8026-F(HSF)

LUBE: AL-8423-L

START: 26 November 1979

END: 14 December 1979

ENGINE OPERATING DATA (AVG)
TEST #23

	Power			Idle
	Min	Max	Avg	(Avg)
Engine Speed, rpm	2796	2815	2804	641
Load, lb	102	111	107	
Torque, lb-ft	177	195	188	
BHp obs	95.3	103.9	100.5	
Fuel Rate, lb/hr	41.5	44.5	43.4	
BMEP, psi	84	92	89	
BSFC lb/BHp-hr	0.418	0.446	0.431	
Temperatures, °F				
Jacket Coolant-In	191	200	198	94
Jacket Coolant Out	198	206	204	102
Oil Sump	246	256	251	
Inlet Air (Blower)	54	84	70	
Exhaust Manifold	910	1020	965	
Fuel @ Return	120	144	139	
Fuel @ Filter	82	96	90	
Pressures				
Oil Gallery, psig	44.0	45.0	44.3	
Blower Discharge, psig	4.5	5.0	4.8	
Intake Vacuum, in. H_2O	6.3	6.8	6.6	
Crankcase, in. H_2O	0.21	0.32	0.26	
Exhaust, Common, in. Hg	2.2	2.7	2.5	
Transfer Pump, psig	71	91	73	
Oil Consumption, lb			53	

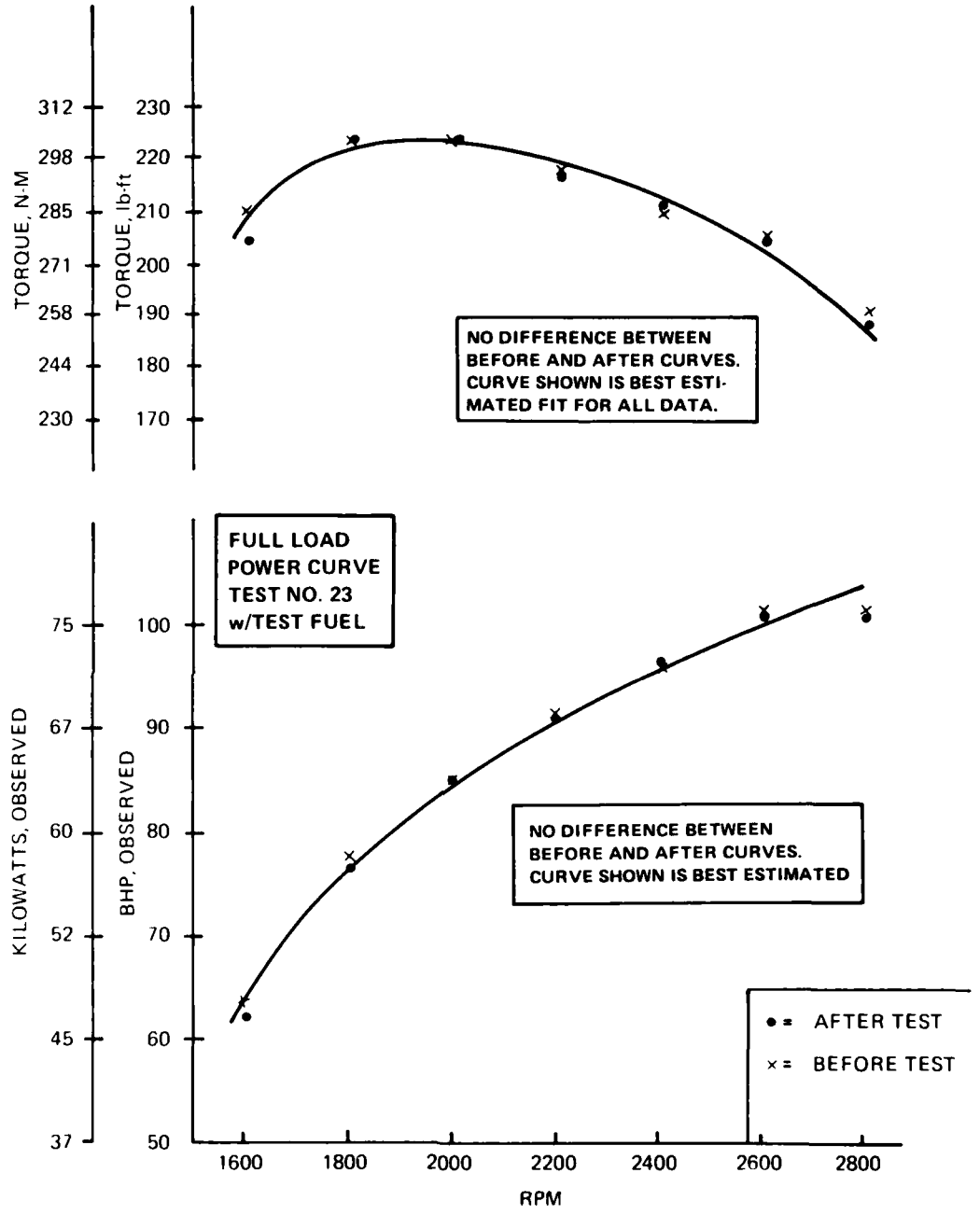
LUBRICANT ANALYSES (AL-8423-L)
TEST #23

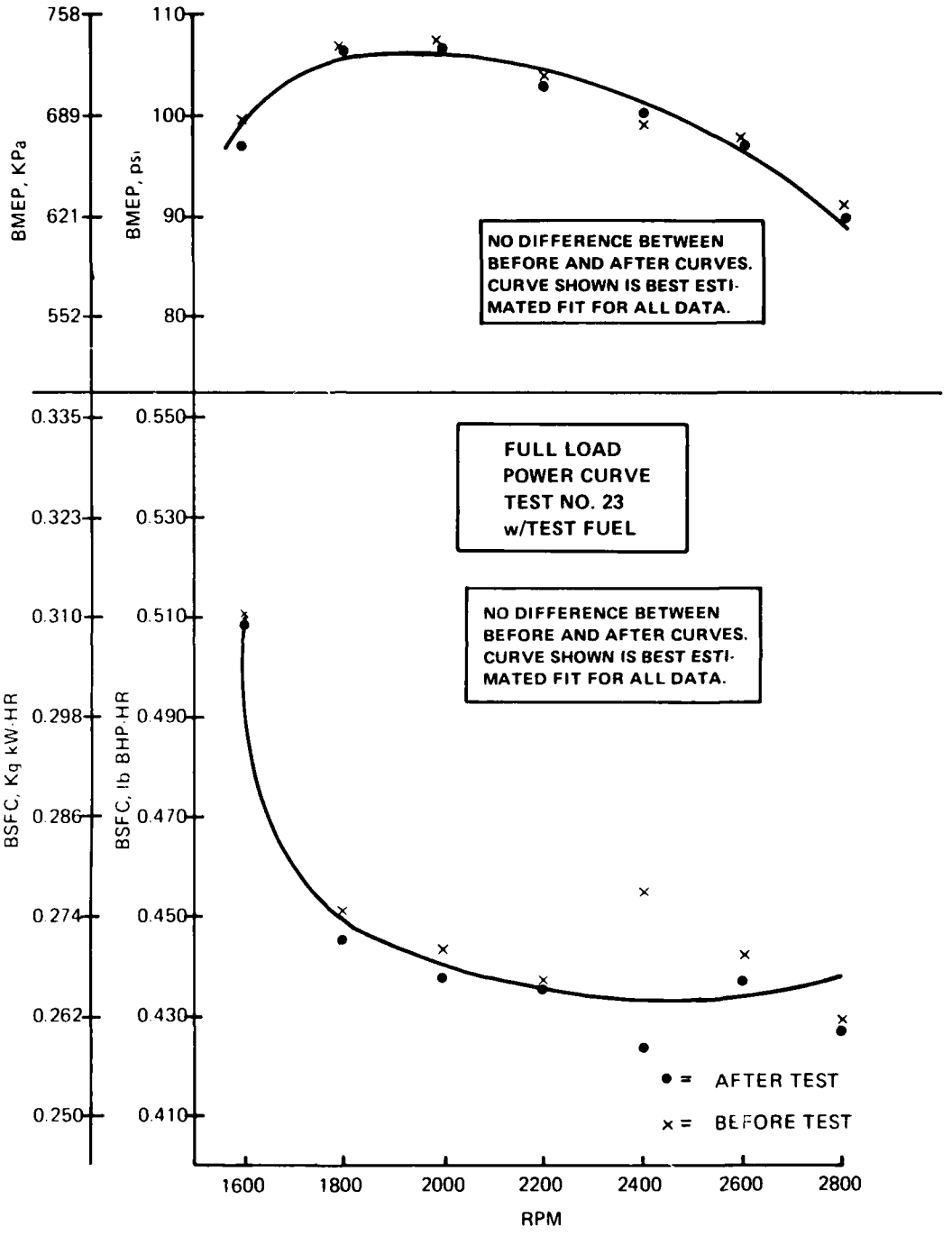
Property	Method	New Oil	70 Hrs	140 Hrs	210 Hrs
K. Vis, cS, 40°C	D 445	77.59	81.02	84.49	85.88
K. Vis, cS, 100°C	D 445	12.97	12.64	13.12	13.42
VI	D 2270	169	155	156	158
TAN	D 664	5.2	4.6	5.3	5.7
TBN	D 2896	11.2	ND	ND	ND
TBN	D 664	8.9	5.5	5.4	5.1
Insolubles, wt%	D 893				
Pentane A		0.02	ND	ND	0.03
Benzene A		0.02	ND	ND	0.03
Pentane B		0.04	ND	ND	0.98
Benzene B		0.07	ND	ND	0.83
API Gravity, °	D 287	24.3	ND	ND	22.4
Flash Point, °C	D 92	198	ND	ND	232
Carbon Residue, wt%	D 524	1.67	2.37	2.71	2.97
Sulfated Ash, wt%	D 874	1.27	1.43	1.61	1.61
Elemental	Method				
Mg, ppm	AA	0.15	ND	ND	ND
Ca, wt%	AA	0.09	ND	ND	ND
Zn, wt%	AA	0.12	ND	ND	ND
Cu, ppm	AA	A	6	9	10
Cr, ppm	AA	A	2	3	3
Pb, ppm	AA	A	11	13	14
Fe, ppm	XRF/AA	A	60/43	89/70	101/88
S, wt%	XRF	0.50	0.58	0.57	0.59
IR Spectrum No.		1787	ND	ND	1788

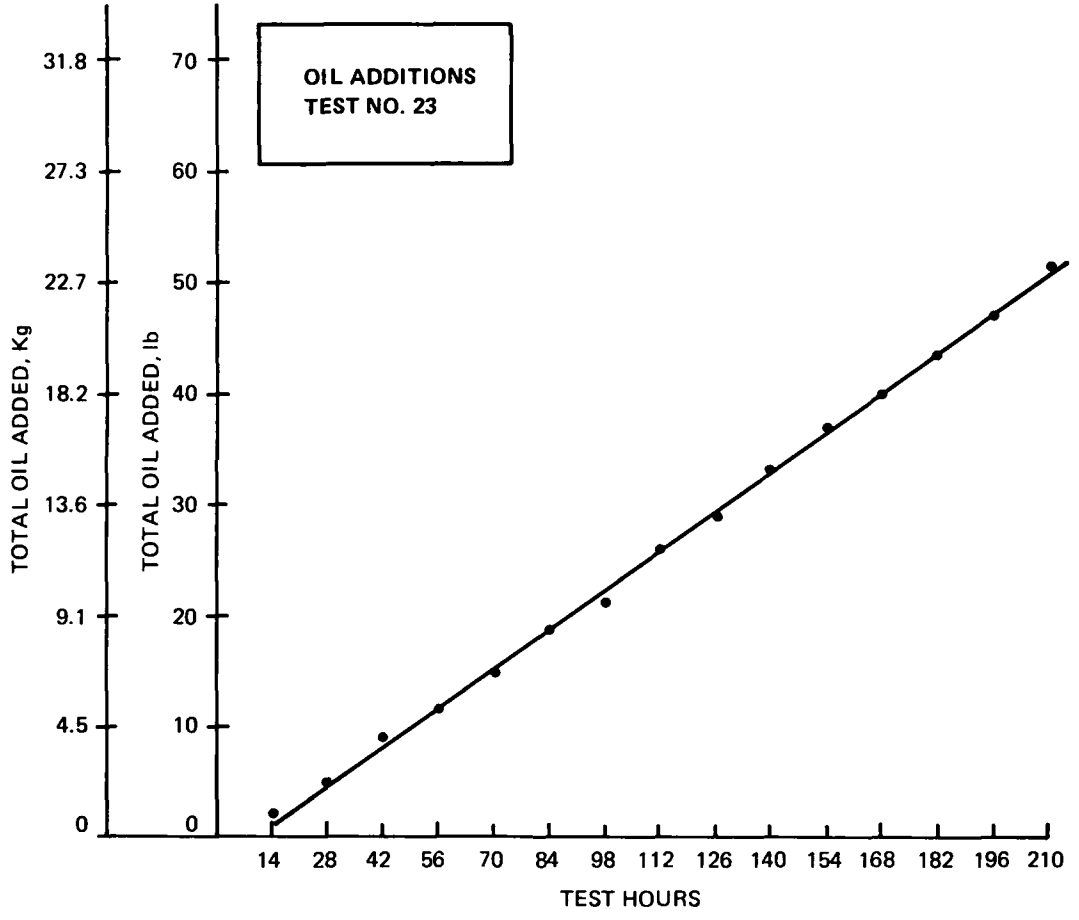
A = Expected to be zero for new oil.
ND = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.

DAILY IRON WEAR METAL BY XRF
TEST #23

Test Hours	Iron ppm
14	24
28	45
42	55
56	55
70	60
84	70
98	67
112	84
126	91
140	89
154	85
168	90
182	102
196	105
210	101


TORQUE, N-M
312
298
285
271
258
244
230
TORQUE, lb-ft
230
220
210
200
190
180
170
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED FIT FOR ALL DATA.
FULL LOAD POWER CURVE TEST NO. 23 w/TEST FUEL
KILOWATTS, OBSERVED
75
67
60
52
45
37
BHP, OBSERVED
100
90
80
70
60
50
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED
● = AFTER TEST
× = BEFORE TEST
1600
1800
2000
2200
2400
2600
2800
RPM


758
689
621
552
BMEP, KPa
110
100
90
80
BMEP, psi
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED FIT FOR ALL DATA.
FULL LOAD POWER CURVE TEST NO. 23 w/TEST FUEL
NO DIFFERENCE BETWEEN BEFORE AND AFTER CURVES. CURVE SHOWN IS BEST ESTIMATED FIT FOR ALL DATA.
0.335
0.323
0.310
0.298
0.286
0.274
0.262
0.250
BSFC, Kg kW-HR
0.550
0.530
0.510
0.490
0.470
0.450
0.430
0.410
BSFC, lb BHP-HR
● = AFTER TEST
× = BEFORE TEST
1600
1800
2000
2200
2400
2600
2800
RPM


OIL ADDITIONS
TEST NO. 23
TOTAL OIL ADDED, Kg
TOTAL OIL ADDED, lb
31.8
27.3
22.7
18.2
13.6
9.1
4.5
0
70
60
50
40
30
20
10
0
14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
TEST HOURS

RING FACE CONDITION: % BURNING
TEST #23

	Cylinder Number		
	1	2	3
First Ring	65*	15	10
Second Ring	80	45	45
Third Ring	60*	50	75
Fourth Ring	50*	50	80
Average of all	52		

N = Normal.
* = Small pieces of metal missing.

RING STICKING
TEST #23

Ring No.	Piston Number		
	1	2	3
1	F	F	F
2	F	F	F
3	F	F	F
4	F	F	F

F = Free

CYLINDER LINERS
TEST #23

Cylinder Number	Percent Port Restriction	Cylinder Liner Scuffing % of Compression Ring Travel Area				
		% Scuffed		% Total		
		Thrust	Anti-Thrust	Area Scuffed	% Glazed	% Lacquer
1	5	30	75	53	5	20
2	2	15	25	20	10	20
3	2	5	55	30	10	30
Average	3	18	52	34	8	23

PISTON O.D. (IN)
TEST #23

Cylinder	1	2	3
Before	3.8708	3.8713	3.8716
After	3.8719	3.8710	3.8710
Change	+0.0009	-0.0003	-0.0006

PISTON SURFACE CONDITION
TEST #23

	Piston Number		
	1	2	3
Top Land	Normal	Normal	Normal
Skirt	Lt scuff & scratches	5% plate melt Lt scuff & scratches	Lt Scuff & scratches
Piston Pin	Normal	Normal	Normal

PISTON GROOVE INSIDE DIAMETER -
% RING SUPPORTING CARBON
TEST #23

Piston Ring	Quadrant	Piston Number 1	2	3
1	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
2	1	20	100	25
	2	0	90	25
	3	0	0	90
	4	100	5	0

Quadrants:
1 = Thrust
2 = Rear
3 = Anti-thrust
4 = Front

EXHAUST VALVE DEPOSITS
TEST #23

Area	Cylinder No. 1	2	3
Head	All 75% - AHC, 25% soot		
Face	All #9 Lacquer to very light carbon		
Tulip	All #9 Lacquer to light carbon		
Stem	All #9 Lacquer to clean		

EXHAUST VALVE SURFACE CONDITIONS
TEST #23

	Cylinder No. 1	2	3
Freeness in Guide	F	F	F
Head	N	N	N
Face	N	N	N
Seat	N	N	N
Stem	N	N	N
Tip	N	N	N

F = Free
N = Normal

RING DEPOSITS
TEST #23

Cylinder Number		1		2		3	
	Ring	CARB	LACQ	CARB	LACQ	CARB	CARB
Top	1	0	100-9	10-½ AHC	10-7 80-9	100-¼ AHC	0
	2	0	25-9 5-6 70-8	0	15-6 85-9	5-¼ AHC	15-9 20-5 50-6
	3	0	100-6	0	100-8	0	100-5
	4	0	100-4	0	100-3	0	100-3
ID	1	100-½ AHC	0	100-AHC	0	100-AHC	0
	2	10 BHC 90 AHC	0	15-BHC 85-AHC	0	15-BHC 85-AHC	0
	3	100-¼ AHC	0	100-½ AHC	0	100-¼ AHC	0
	4	50-¼ AHC	50-6	0	100-9	0	100-8
Bottom	1	0	5-8 5-6	0	20-7	0	20-6 5-9
	2	0	5-9 5-6	0	30-5	0	20-4
	3	0	5-4	0	75-3	0	100-3
	4	0	50-2	0	100-2	0	100-2

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8423-L

RATER LYONS DATE 12-27-79
LABORATORY TEST NUMBER 3-53 #23
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8926-F
1% S, DF-2

PISTON NO. 1

NO. 1 GROOVE, VOLUME-%	
PISTON WTD* RATING	340

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	GROOVES NO. 1 DEMERIT	GROOVES NO. 2 AREA-%	GROOVES NO. 2 DEMERIT	GROOVES NO. 3 AREA-%	GROOVES NO. 3 DEMERIT	GROOVES NO. 4 AREA-%	GROOVES NO. 4 DEMERIT	LANDS NO. 1 AREA-%	LANDS NO. 1 DEMERIT	LANDS NO. 2 AREA-%	LANDS NO. 2 DEMERIT	LANDS NO. 3 AREA-%	LANDS NO. 3 DEMERIT	LANDS NO. 4 AREA-%	LANDS NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00											25	25.00	5	5.00				
	MHC	0.75			100	75.00	20	15.00												
	MC	0.50	85	42.50			80	40.00					75	37.50	90	45.00				
	LC	0.25	15	3.75							100	25.00					15	3.75		
	VLC	0.15							100	15.00										
	CARBON RATING		46.25		75.00		45.00		15.00		25.00		62.50		50.00		3.75			
LACQUER	BL	0.100													5	.50	10	1.00	100	10.00
	DBrL	0.075															75	5.625		
	AL	0.050																		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING														.50		6.625			
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			46.25		75.00		45.00		15.00		25.00		62.50		50.50		10.375		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8423-L

RATER LYONS DATE 12-27-79
LABORATORY TEST NUMBER 3-53 #23
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8926-F
1% S, DF-2

PISTON NO 2

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	310

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	LANDS NO. 1 AREA-%	NO. 1 DEMERIT	NO. 2 AREA-%	NO. 2 DEMERIT	NO. 3 AREA-%	NO. 3 DEMERIT	NO. 4 AREA-%	NO. 4 DEMERIT	UNDER-CROWN AREA-%	UNDER-CROWN DEMERIT
CARBON	HC	1.00			60	60.00					15	15.00	75	75.00	10	10.00				
	MHC	0.75																		
	MC	0.50	50	25.00	40	20.00														
	LC	0.25	50	12.50			25	6.25			85	21.25	25	6.25	80	20.00	5	1.25		
	VLC	0.15					75	11.25												
	CARBON RATING		37.50		80.00		17.50				36.25		81.25		30.00		1.25			
LACQUER	BL	0.100							100	10.00					10	1.00	15	1.50	100	10.00
	DBrL	0.075																		
	AL	0.050															80	4.00		
	LAL	0.025																		
	VLAL	0.010																		
	RL	0.001																		
	LACQUER RATING								10.00						1.00		5.50			
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			37.50		80.00		17.50		10.00		36.25		81.25		31.00		6.75		10.00	

*WEIGHTED TOTAL DEPOSITS

CRC DIESEL RATING SYSTEM

STANDARD COMPUTATION SHEET FOR PISTON RATING

TEST PROCEDURE _____
TEST HOURS 210
TEST LABORATORY AFLRL
LUBRICANT AL-8423-L

RATER LYONS DATE 12-27-79
LABORATORY TEST NUMBER 3-53 #23
STAND NO. 2 ENGINE NO. 3D-131703
FUEL AL-8926-F
1% S, DF-2

PISTON NO. 3

NO. 1 GROOVE, VOLUME %	
PISTON WTD* RATING	305

DEPOSIT TYPE		DEPOSIT FACTOR	GROOVES								LANDS								UNDER-CROWN	
			NO. 1		NO. 2		NO. 3		NO. 4		NO. 1		NO. 2		NO. 3		NO. 4			
			AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT	AREA-%	DEMERIT
CARBON	HC	1.00			50	50.00	15	15.00			10	10.00	90	90.00	10	10.00				
	MHC	0.75																		
	MC	0.50																		
	LC	0.25	100	25.00	50	12.50	85	21.25	10	2.50	90	22.50	10	2.50	90	22.50	10	2.50		
	VLC	0.15															10	1.50		
	CARBON RATING		25.00		62.50		36.25		2.50		32.50		92.50		32.50		4.00			
LACQUER	BL	0.100							45	4.50							5	.50	100	10.00
	DBrL	0.075																		
	AL	0.050																		
	LAL	0.025							45	1.125										
	VLAL	0.010															75	.75		
	RL	0.001																		
	LACQUER RATING								5.625								1.25		10.00	
CLEAN		0																		
ZONAL RATING																				
LOCATION FACTOR																				
WEIGHTED RATING			25.00		62.50		36.25		8.125		32.50		92.50		32.50		5.25		10.00	

*WEIGHTED TOTAL DEPOSITS

CYLINDER LINER I.D. (IN)
TEST #23

Cylinder No.		Front/Back Parallel to Crank Top	Front/Back Parallel to Crank Middle	Front/Back Parallel to Crank Bottom	Thrust/Antithrust Perpendicular to Crank Top	Thrust/Antithrust Perpendicular to Crank Middle	Thrust/Antithrust Perpendicular to Crank Bottom
1.	After	3.8761	3.8760	3.8752	3.8797	3.8762	3.8756
	Before	3.8759	3.8761	3.8756	3.8761	3.8760	3.8757
	Change	0.0002	-0.0001	-0.0004	0.0036	0.0002	-0.0001
2.	After	3.8766	3.8764	3.8764	3.8780	3.8767	3.8764
	Before	3.8764	3.8765	3.8763	3.8767	3.8767	3.8765
	Change	0.0002	-0.0001	0.0001	0.0013	0.0000	-0.0001
3.	After	3.8767	3.8765	3.8757	3.8785	3.8770	3.8765
	Before	3.8764	3.8768	3.8762	3.8765	3.8769	3.8765
	Change	0.0003	-0.0003	-0.0005	0.0020	0.0001	0.0000

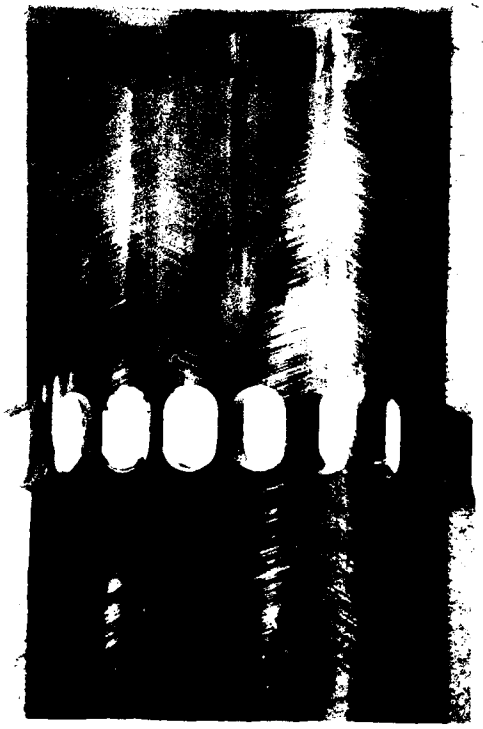
Average (All) 0.0008 In.
Average T/AT 0.0008 In.

PISTON RING GAP (IN)
TEST #23

Piston No.		Ring No. 1	2	3	4	5	6	7	8
1.	After	0.044	0.026	0.028	0.029	0.023	0.023	0.022	0.024
	Before	0.038	0.026	0.028	0.028	0.020	0.021	0.020	0.020
	Change	0.006	0.000	0.000	0.001	0.003	0.002	0.002	0.004
2.	After	0.042	0.029	0.028	0.030	0.025	0.023	0.023	0.022
	Before	0.038	0.029	0.029	0.030	0.021	0.020	0.020	0.020
	Change	0.004	0.000	-0.001	0.000	0.004	0.003	0.003	0.002
3.	After	0.037	0.028	0.028	0.026	0.025	0.022	0.025	0.022
	Before	0.032	0.027	0.027	0.026	0.022	0.020	0.020	0.020
	Change	0.005	0.001	0.001	0.000	0.003	0.002	0.005	0.002

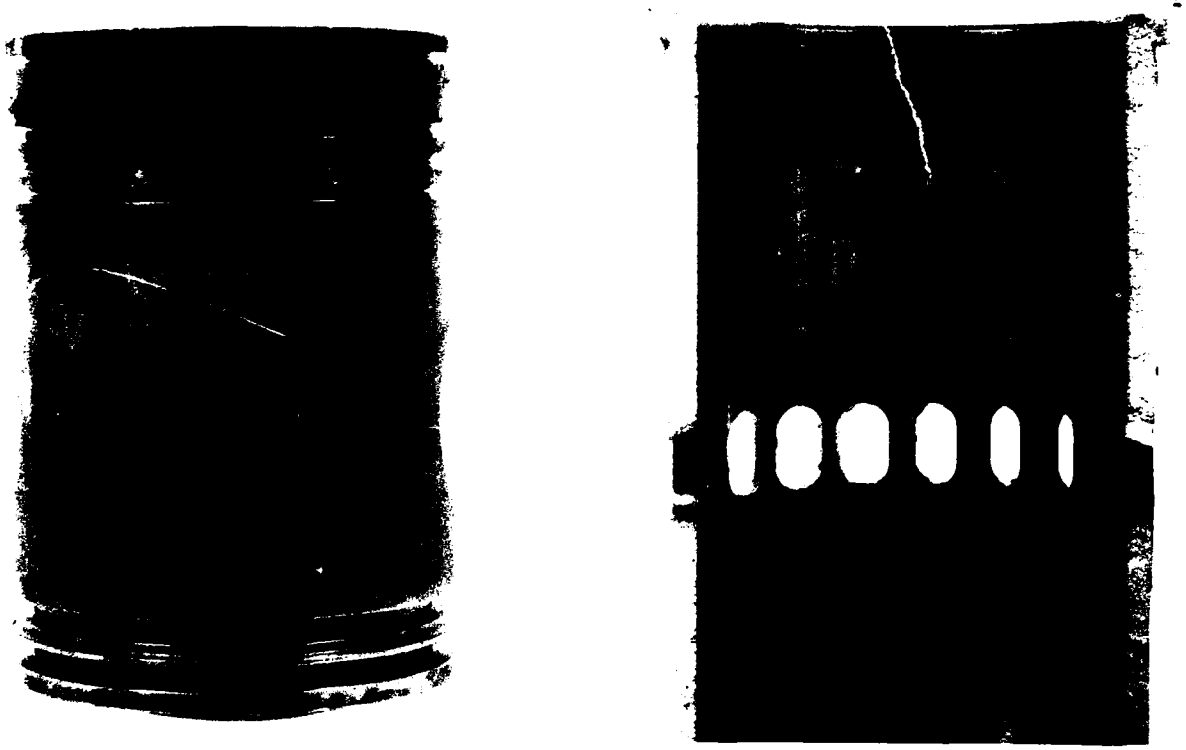
Avg F/R (#1) Wear 0.005 In.

PISTON AND CYLINDER LINER CONDITION
Test #23



No. 1 - Thrust Side
(Average)

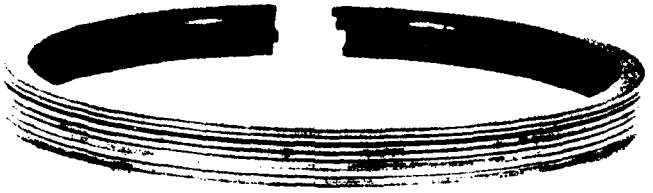
PISTON AND CYLINDER LINER CONDITION
Test #23



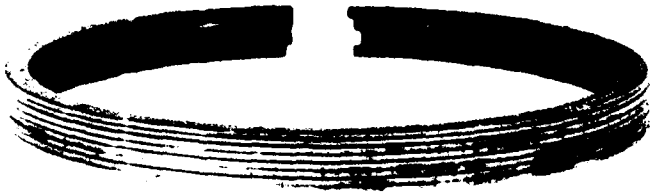
No. 1 - Anti-Thrust Side
(Worst)

RING FACE CONDITION
Test #23

Piston - 1



Piston - 2



Piston - 3

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FORT BENNING GA 31905

CDR
US ARMY AVIATION CTR & FT RUCKER
ATTN ATZQ-D 1
FORT RUCKER AL 36362

DEPARTMENT OF THE NAVY

CDR
NAVAL AIR PROPULSION CENTER
ATTN PE-71 1
PE-72 (MR D'ORAZIO) 1
P O BOX 7176
TRENTON NJ 06828

CDR
NAVAL SHIP ENGINEERING CTR
CODE 6101F (MR R LAYNE) 1
WASHINGTON DC 20362

CDR
DAVID TAYLOR NAVAL SHIP R&D CTR
CODE 2830 (MR G BOSMAJIAN) 1
CODE 2831 1
ANNAPOLIS MD 21402

JOINT OIL ANALYSIS PROGRAM -
TECHNICAL SUPPORT CTR 1
BLDG 780
NAVAL AIR STATION
PENSACOLA FL 32508

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
ATTN LPP (MAJ SANBERG) 1
LMM (MAJ GRIGGS) 1
WASHINGTON DC 20380

CDR
NAVAL AIR SYSTEMS CMD
ATTN CODE 52032E (MR WEINBURG) 1
CODE 53645 1
WASHINGTON DC 20361

CDR
NAVAL AIR DEVELOPMENT CTR
ATTN CODE 60612 (MR L STALLINGS) 1
WARMINSTER PA 18974

CDR
NAVAL RESEARCH LABORATORY
ATTN CODE 6170 (MR H RAVNER) 1
CODE 6180 1
CODE 6110 (DR HARVEY) 1
WASHINGTON DC 20375

CDR
NAVAL FACILITIES ENGR CTR
ATTN CODE 1202B (MR R BURRIS) 1
CODE 120B (MR BUSCHELMAN) 1
200 STOVALL ST
ALEXANDRIA VA 22322

CHIEF OF NAVAL RESEARCH
ATTN CODE 473 (DR R MILLER) 1
ARLINGTON VA 22217

CDR
NAVAL AIR ENGR CENTER
ATTN CODE 92727 1
LAKEHURST NJ 08733

CDR
NAVY FACILITIES ENGRG CMD
CIVIL ENGR SUPPORT OFC
CODE 15312A (ATTN EOC COOK) 1
NAVAL CONSTRUCTION BATTALION CTR
PORT HUENEME CA 93043

CDR, NAVAL MATERIAL COMMAND
ATTN MAT-08T3 (DR A ROBERTS) 1
CP6, RM 606
WASHINGTON DC 20360

CDR
NAVY PETROLEUM OFC
ATTN CODE 40 1
CAMERON STATION
ALEXANDRIA VA 22314

CDR
MARINE CORPS LOGISTICS SUPPORT
BASE ATLANTIC
ATTN CODE P841 1
ALBANY GA 31704

DEPARTMENT OF THE AIR FORCE

HQ, USAF
ATTN RDPT 1
WASHINGTON DC 20330

HQ AIR FORCE SYSTEMS CMD
ATTN AFSC/DLF (LTC RADLOF) 1
ANDREWS AFB MD 20334

CDR
US AIR FORCE WRIGHT AERONAUTICAL LAB
ATTN AFWAL/POSF (MR CHURCHILL) 1
AFWAL/POSL (MR JONES) 1
WRIGHT-PATTERSON AFB OH 45433

CDR
USAF SAN ANTONIO AIR LOGISTICS CTR
ATTN SAALC/SFQ (MR MAKRIS) 1
SAALC/MMPRR (MR ELLIOT) 1
KELLY AIR FORCE BASE, TX 78241

CDR
US AIR FORCE WRIGHT AERONAUTICAL LAB
ATTN AFWAL/MLSE (MR MORRIS) 1
AFWAL/MLBT 1
WRIGHT-PATTERSON AFB OH 45433

CDR
USAF WARNER ROBINS AIR LOGISTIC CTR
ATTN WR-ALC/MMIRAB-1 (MR GRAHAM) 1
ROBINS AFB GA 31098

OTHER GOVERNMENT AGENCIES

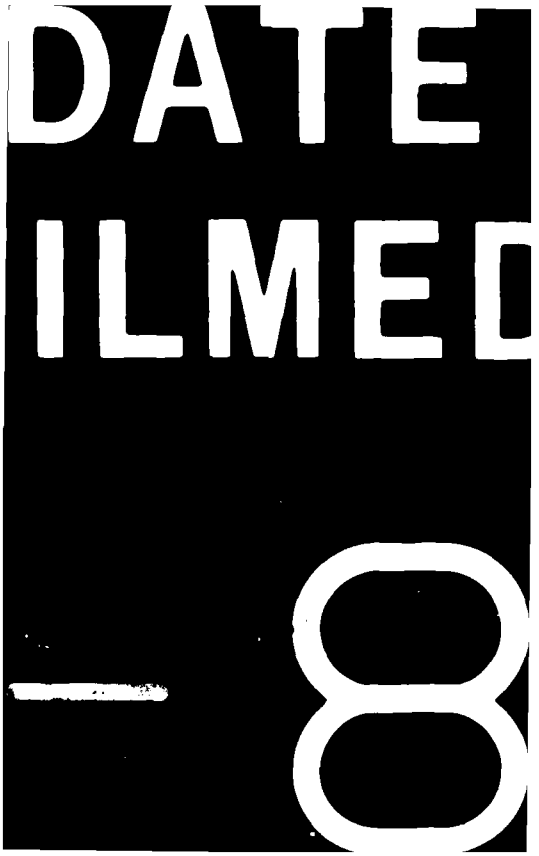
US DEPARTMENT OF TRANSPORTATION
ATTN AIRCRAFT DESIGN CRITERIA BRANCH 2
FEDERAL AVIATION ADMIN
2100 2ND ST SW
WASHINGTON DC 20590

US DEPARTMENT OF ENERGY
DIV OF TRANS ENERGY CONSERV 2
ALTERNATIVE FUELS UTILIZATION BRANCH
20 MASSACHUSETTS AVENUE
WASHINGTON DC 20545

DIRECTOR
NATL MAINTENANCE TECH SUPPORT CTR 2
US POSTAL SERVICE
NORMAN OK 73069

US DEPARTMENT OF ENERGY
BARTLESVILLE ENERGY RSCH CTR
DIV OF PROCESSING & THERMO RES 1
DIV OF UTILIZATION RES 1
BOX 1398
BARTLESVILLE OK 74003

SCI & TECH INFO FACILITY
ATTN NASA REP (SAK/DL) 1
P O BOX 8757
BALTIMORE/WASH INT AIRPORT MD 21240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